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AN ECONOMIC ANALYSIS OF THE RELEVANT COSTS IN AIR FORCE BUILDING REPLACEMENT

Melville M. Andrews, Jr., et al

Air Force Institute of Technology
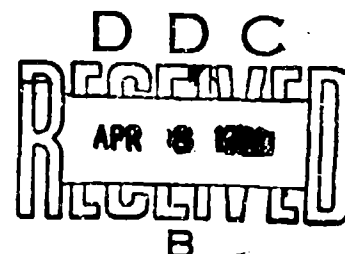Wright-Patterson Air Force Base, Ohio

January 1974

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Deferred Maintenance						

AN ECONOMIC ANALYSIS OF THE RELEVANT COSTS

IN AIR FORCE BUILDING REPLACEMENT

Melville M. Andrews, Jr., Captain, USAF
Jack L. Joines, Captain, USAF

This thesis describes and analyzes the relevant costs in an Air Force building replacement consideration and illustrates, through the use of economic analysis, the effects of the described relevant costs on the replacement decision. A regression analysis is accomplished to illustrate a method of predicting building maintenance expenditures. Building deterioration, obsolescence, and effectiveness are discussed in terms of their effects on maintenance costs and the performance of the assigned function. An economic analysis of a hypothetical replacement consideration illustrates the sensitivity of the replacement decision to inclusion of the costs of obsolescence and reduced functional performance. Deferred maintenance is assessed in terms of its effect on functional performance. The authors conclude that the attendant costs of deterioration, obsolescence, and facility ineffectiveness are essential to a creditable facility replacement decision.

ii

AN ECONOMIC ANALYSIS OF THE

RELEVANT COSTS IN AIR FORCE

BUILDING REPLACEMENT

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Facilities Management

By

M. M. Andrews, Jr., BS   J. L. Joines, BS
Captain, USAF   Captain, USAF

January 1974

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This thesis, written by

Captain M. M. Andrews, Jr.

and

Captain J. L. Joines

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

CHAPTER I

INTRODUCTION

Statement of Purpose

The Department of Defense, as a whole, has often been criticized
for its bureaucratic inefficiency. Senator William Proxmire is one
of the most vocal critics of the Defense Department's management of
public funds.

> Many of those anxious to provide their country with
> all the weapons and security it needs are, nonetheless,
> appalled at the wasteful procedures and inefficient
> management of the Pentagon [Department of Defense].
> (32:218)

The necessity for increased efficiency and cost-consciousness
within the Air Force was amply summarized by General George S.
Brown, USAF Chief of Staff, in a recent address to the National
Security Industrial Association:

> All of us must recognize certain basic truths. First,
> defense costs, like costs everywhere, have been
> climbing steadily. Second, even if defense spending
> could be maintained at a fixed level in current dollar
> terms, there is an erosion of real purchasing power.
> Third, this has necessitated reduction in force size.
> Fourth, the reduced force structure makes it more
> than ever imperative to offset numerical inferiority
> with qualitatively superior weapon systems. But,
> fifth, the cost of these systems has also been climbing

so rapidly that we face such alternatives as reduced
quality, lesser numbers, or just not going forward
at all with some programs that are needed. These
factors can only degrade the effectiveness of our
defense forces, unless we move in the direction of
greatly increased efficiency in the way we do business.
Cost-consciousness--cost avoidance--cost reduction
will have to be our way of life. (6:761)

Since it is incumbent upon all Air Force resource managers to

control and direct the application of resources in an efficient manner,

an awareness and willingness to utilize analytical techniques in

resource allocation decisions is essential.

Hitch and McKean indicated that increased reliance on systematic

quantitative analysis is required in the Department of Defense to

determine the most efficient allocation of resources. (22:107) A

lecturer at the Air Force's Air War College recently pointed out a

similar need for economic awareness:

With the increasing awareness of scarcity, it would
seem that to our "fly and fight" motto we might want
to add "efficiently." Given that we have defined a
specific role, mission, or objective, our mandate is
clearly to fulfill that role or achieve that objective
at minimum cost. Similarly, given the public funds
(resources) entrusted to us, we have a vital responsi-
bility to maximize the military returns from those
inputs. It is the economics discipline that advises
the resources to be combined in various ways to
achieve those elusive optima. (50:33)

The importance of using analytical techniques which embody the

theories of economics has been stressed above, but how can this be

applied to the decision process of resource allocation? It can be

applied through the use of economic analysis.

Economic analysis is a systematic approach which assists the manager in obtaining a solution to a given problem based upon a thorough evaluation of the costs and benefits of various alternatives available to accomplish desired objectives. (14:5)

As the designated Air Force manager of real property assets, the base civil engineer is charged, among other things, with the responsibility of economically maintaining all facilities accounted for as real property assets. Under certain circumstances, the economically superior alternative to continued maintenance may be replacement of an aging real property facility. There are, of course, numerous fe rs which must be taken into consideration in making a replacement decision regarding an Air Force facility.

The basic alternatives available in the replacement decision are: (1) retain the facility as is and continue to maintain it; (2) rehabilitate the facility--rehabilitation is defined as bringing the facility up to current standards in terms of construction, layout, and technology; and (3) replacing the entire facility with an up-to-date, modern, technologically sufficient facility.

The authc s nd to identify the major cost elements involved in each c the above mentioned alternatives and to identify how each of these cost eleme s affects a specified alternative. Then, an example illustrating the us of economic analysis to determine the economically superior alternative is presented.

To provide a common frame of reference, the following terms
are defined as they are used herein:

Economic Analysis. --A systematic approach which assists the
manager in determining a solution to a given problem based upon
a thorough evaluation of the costs and benefits of various alter-
natives available to accomplish desired objectives. (14:5)

Real Property Facility. --A separate real property building or
structure or other real property improvement to which a
specific six-digit real property category code (AFM 300-4,
Vol IV, Part II, ADE RE-008, 8 November 1968) has been
assigned for inventory purposes. These codes constitute a
method of identifying the functional use of the facility. (46:2)
For purposes of this study, the term "facility" will apply only
to buildings.

Installation. --A separately located and defined area of real
property in which the Air Force exercises a real property
interest, or where the Air Force has jurisdiction over real
property by agreement with foreign governments or by rights
of occupation. (46:2)

Investment. --The sum of money or capital employed for a
given purpose or in a given area; a security or other property
right purchased or otherwise acquired or the cost of acquisi-
tion thereof. An investment is an acquisition made in the
expectation of realizing benefits. (47:2)

Economic Life. --The length of time a given facility holds
economic superiority compared to alternate facilities
in terms of the combined costs of owning, operating, and
maintaining.

Repair. --Restoring a failed or failing real property facility
or component thereof so that the output or service provided
by the function which occupies the facility is not impaired
or reduced. Repair includes restoring or replacing compon-
ents of facilities damaged by fire, storm, explosion, the
elements, and other disasters. Repair also consists of over-
haul, reprocessing, or replacing deteriorated constituent
parts, equipment, or materials which cannot be corrected
through maintenance. (46:3)

Maintenance. --The recurrent, day-to-day, periodic or
scheduled work required to preserve or restore a real

property facility so that it may be used effectively for its
designated purpose. It includes work required to restore
components which have deteriorated from fair wear and
tea., and other work on a facility to prevent damage or
deterioration to that facility which otherwise would be
more costly to restore. (46:2) For purposes of this study,
the term "maintenance" will include repair.

Operation Costs. --The cost associated with providing utilities
to support a facility, i.e., water, heat, electricity, and air
conditioning.

Replacement. --Construction of a real property facility to be
used in place of a similar facility destroyed, damaged, or
deteriorated beyond the point at which it may be economically
repaired. (46:2)

Performance. --The capacity to achieve the desired result, i.e.,
a measure of performance, would compare the quantity or
quality of output or service produced to that required by stan-
dard in order to achieve mission accomplishment.

Effectiveness. --The capacity to accomplish stated goals, i.e.,
providing the quantity and quality of output or service required
for mission accomplishment.

Cost-Effectiveness. --The capacity to accomplish stated goals
with a minimum expenditure of resources (e.g., time, money,
manpower, materials).

Efficiency. --The ability to produce the maximum amount of
output from a minimum amount of resources.

Productivity. --The physical output produced per unit of
productive effort.

Background

As shown by Table 1-1, the undepreciated value of the current

Air Force real property inventory is approximately 17 billion dollars.

This value is based on original facility construction costs plus subse-

quent capital improvements. Table 1-1 also reflects the growth of

the Air Force real property plant required to support expanding missions and technology. These facilities provide the physical environment which supports the Air Force mission. Therefore, the efficient application of the resources available for facility operation, maintenance, and construction is of paramount importance.

TABLE 1-1

NUMBER AND UNDEPRECIATED DOLLAR VALUE OF
AIR FORCE REAL PROPERTY FACILITIES*
1957-1972 (26)

Yr	#Fac**	$ (Millions)	Yr	#Fac**	$ (Millions)
57	127,677	$ 7,241	65	160,646	$15,989
58	130,057	3,561	66	160,612	16,752
59	141,782	9,684	67	157,503	17,141
60	155,904	11,454	68	155,385	16,655
61	162,244	13,090	69	151,648	16,442
62	163,470	14,191	70	149,825	16,506
63	166,104	14,980	71	145,867	16,490
64	160,823	15,886	72	145,513	16,800

*Buildings only.
**Reduction in number of facilities beginning in 1964 attributable to
reduction in Air Force installations from approximately 4,000 to
3,000. The above table applies to Air Force facilities, world-wide.

The efficient application of civil engineering resources requires continuous evaluation to determine the economic lives of facilities. When facilities are retained beyond their economic lives, the inherent costs of the economically inferior alternative must be recognized.

In many instances, facilities are retained beyond their economic lives. This happens in some cases because management lacks the

initiative to determine the loss of economic advantage. In other cases, management is aware that the original facility has lost its economic advantage; however, funds for the economically superior alternative are preempted by higher priority requirements, and continued use is a forced alternative.

The base civil engineer must be aware of the ramifications of expending dollars for continued use of a facility when it is more economical to rehabilitate or replace it. If, due to higher priority requirements, the base civil engineer is forced to continue to maintain a facility even though it has exceeded its economic life, he can use economic analysis to provide quantitative justification for the required maintenance funds.

What are the effects of continued use of a facility beyond its economic life? Operation and maintenance (O&M) costs can be expected to increase with age. If increased O&M funding is not forthcoming, the rate of physical deterioration can be expected to increase and the facility will fail to provide for functional efficiency. The result is increased maintenance costs and a deterioration in either the quantity or quality of output produced by the function assigned to the facility. This reduction in quantity or quality of output represents a cost that must be absorbed at some level within the Department of Defense.

William T. Morris, Professor of Industrial Engineering at The Ohio State University, has made the following observation regarding the consequences of an inadequate replacement policy in the private

sector:

> The consequences of an inadequate replacement policy for
> the firm are potentially disastrous. If the replacement is
> postponed beyond a reasonable time, the firm may find
> that its production costs rise, whereas the costs of its
> competitors who are using more modern equipment are
> declining. Thus, the firm is no longer able to meet
> price competition, and finds it impossible either to
> earn or borrow the funds with which to replace its
> machines. This is a technological and economic trap
> from which escape can be made only through the most
> drastic means. (29:142)

Although Professor Morris's comments are directed at private enter-

prise, it is not difficult to draw a parallel to the defense environment.

In the absence of a profit incentive and competition, it becomes

extremely convenient for the Defense Department to accept escalating

production costs and efficiency losses year after year. The accept-

ance of inefficiency within the Department of Defense is convenient

because in most operations an objective criterion of efficiency is not

readily available, and even if it were, incentives to seek profitable

innovations and efficient methods are not strong. In addition, the

costs of selecting inefficient alternatives do not impinge on the

decision-maker. (22:106)

TABLE 1-2

AGE OF AIR FORCE REAL
PROPERTY FACILITIES* (26)

AGE	Nr of Facilities	Per Cent
Over 24 Years	18,376	16.5
14-23 Years	51,486	46.4
3-13 Years	35,747	32.2
2 Years or Less	5,481	4.9
TOTAL	111,090	100.

*Applies only to buildings within CONUS.

Table 1-2 illustrates that 62.9% of the facilities in the current Air Force inventory are in excess of 14 years old. Of these facilities, approximately 26% are in excess of 24 years of age. The advancing age of the facilities inventory, the attendant increase of maintenance cost, and the decreased efficiency of operation of the functions which occupy the facilities, indicate a requirement for periodic assessment of the costs associated with continued occupancy of these facilities. Assessing these costs comprises a replacement consideration.

Scope

The facilities available within the Air Force for accomplishment of the mission are the legacy of past decisions. The dynamic nature of the Air Force mission requires flexibility and an ability to respond to technological advances, personnel increases and decreases, and changes in administration policies. The response to changing requirements is affected by the limitations of imposed budgets. Under these circumstances, the base civil engineer must have the capability to evaluate the attendant costs of alternative methods in order to provide economical mission support.

Although the timely response to changing mission requirements is important, the efficient management of the existing real property inventory is even more important. This requires an awareness of the effects of deterioration and obsolescence on future operation and maintenance costs, as well as the combined effect of deterioration

and obsolescence on the capability of the facility to provide an environment for efficient functional performance.

Fixed assets have terminable lives; however, they do not disappear at the end of these predetermined periods. (40:410) As previously defined, the economic life of a facility generally depends upon changes in operation and maintenance costs, technological obsolescence when compared to newer facilities, and changes in mission which require modification of the facility. A major problem involving investment in fixed assets is determining when they should be replaced. The decision to replace facilities must be based on an evaluation of all the relevant costs associated with continued use, rehabilitation, and replacement.

At present, an economic analysis is suggested by DOD for all major acquisition investments. Formal submission of an economic analysis is required (in facility acquisition) when replacing a facility through the Military Construction Programs (MCPs) or when a construction proposal costing $300,000 or less can be amortized within three years, i.e., the benefits to be derived from the project within three years of completion must equal or exceed the investment cost.

It is the authors' contention that, except for O&M costs, other relevant costs such as obsolescence and loss of facility effectiveness are not adequately considered in current Air Force facility replacement decisions. Therefore, it is the expressed purpose of this research effort to describe those relevant costs and show how their

consideration can affect the theoretical economic analysis of replacement/rehabilitation decisions.

Method

A creditable facility replacement decision can only be made when the decision maker is fully aware of the relevant costs which affect the decision. In addition, the decision maker must fully understand the procedures which can be used to explicitly view the decision. This thesis is therefore structured to describe and analyze the relevant costs in the facility replacement consideration and to illustrate the effects of these relevant costs on the replacement decision.

A regression analysis is accomplished to illustrate a method of determining and predicting expected annual maintenance costs, which are essential elements in a replacement decision. In addition to annual maintenance costs, a description and analysis of additional relevant costs required in the replacement decision is developed. The impact of all the relevant costs on the replacement decision is assessed using economic analysis. Finally, the impact of funding constraints on maintenance requirements is discussed in terms of its affect on the loss of performance.

Expected annual maintenance costs. --The amount of money spent annually to maintain a facility represents a major annual cost to provide the service or output of the assigned function. Before the economics of the facility replacement question can be rationally

addressed, a method must be developed to predict the expected annual maintenance expenditures for a facility.

The authors believe that the following facility characteristics represent three major variables which influence annual facility maintenance costs:

1. Age

2. Size

3. Functional use

Although other variables, such as type of construction, general facility condition, and maintenance policy, can and do affect annual maintenance costs, this research effort addresses only the above mentioned variables since data for the population of interest are not available in the detail required.

To facilitate a means of predicting expected annual maintenance expenditures, multiple regression analysis is used to determine coefficients for the variables. The resulting regression equation allows prediction of expected annual maintenance expenditures within a specified variance.

For purposes of this regression analysis, the statistical universe is considered to be all buildings within the current Air Force CONUS real property inventory. The statistical population of interest is limited to buildings on Myrtle Beach Air Force Base, except for military family housing and facilities less than 2,000 square feet in size. The population is limited to a single base so that external

variables such as climatic conditions, size of the maintenance work force, mission requirements, etc., can be considered constant.

The data used in the regression analysis are taken from FY 73 cost and real property records for facilities on Myrtle Beach AFB. Maintenance expenditures on these facilities were collected through the Base Engineer Automated Management System (BEAMS) at Myrtle Beach AFB.

Cost factors to be considered in the replacement decision. --The major cost determinants which affect the economic life of a facility are deterioration, obsolescence, and facility ineffectiveness. Due to the difficulty involved in measuring these cost determinants, it is necessary to use key facility characteristics as proxies (age, size, and function are used in Chapter II for the regression analysis) to determine the effects of deterioration and obsolescence on facility maintenance costs. The singular and combined effects of these factors must be understood and their attendant costs estimated, either quantitatively or qualitatively, before the economic superiority of an existing or proposed facility can be evaluated.

The types of physical deterioration, their effects on a facility, and their trends over time are direct determinants of the facility's annual operation and maintenance costs.

Use of technological improvements in building materials, equipment, and systems as well as new and improved organization operating policies and procedures can provide significant benefits

over existing conditions. That is to say, existing facility operation and maintenance costs can be reduced by incorporation of newer facilities or components. Likewise, new innovations of organizational setup or procedures can increase output and/or improve efficiency.

The combined effects of deterioration and obsolescence result in a third major cost determinant, facility ineffectiveness. This determinant, although a result of the other two, is considered to be a major determinant since it causes a loss in performance of the function occupying the facility. This loss in performance must be considered a relevant cost. The cost attributable to this factor is represented by an increase in operation and maintenance costs to provide the required output or service, or a decrease in the quantity or quality of the output required for mission accomplishment. This cost, which is most difficult to measure, is seldom considered in replacement decisions today.

Very little research is available which outlines the inter-relationships of deterioration, obsolescence, and facility ineffectiveness and their application to the replacement of facilities. However, current literature does provide extensive coverage of these concepts in connection with the replacement of equipment. Therefore, using available research on equipment replacement, the authors extend the concepts to the replacement of facilities and explain how their combined effects can affect the economic life of a facility.

Economic analysis. --The authors contend that annual operations
and maintenance costs and costs resulting from obsolescence and loss
in performance are major costs incurred in the continued habitation of
a facility beyond its economic life. The time-adjusted sum of these
costs over a facility's expected life represent the present value of all
future costs of the "continued use" alternative.

For the replacement alternative, the cost for a new facility
can be computed using the standard Air Force construction price
indices for major classifications of buildings. The investment cost
plus the present value of all future costs of replacement or rehabili-
tation provides the total present value cost for these two alternatives.
When the total present value of all costs resulting from each alterna-
tive are computed and compares, the alternative with the least present
value cost is the economically superior.

The authors (1) develop the theoretical foundation for the use
of present value analysis, (2) apply present value analysis to each
alternative, (3) illustrate the method of determin g the economically
superior alternative in the replacement decision, and (4) analyze and
explain the economic advantages of each alternative.

Deferred maintenance. --A problem which complicates the Air
Force's ability to combat the effects of deterioration, obsolescence,
and facility ineffectiveness on its facility plant is the lack of adequate
funding to accomplish all requirements. The resultant backlog of
requirements can have an effect on the deterioration rate and the

performance of the assigned function. The present Air Force defini-
tion of deferred maintenance is assessed and the key terms used in
the classification of deferred maintenance, such as "essential mainte-
nance," "impairment of military readiness and capability," and
"proper facility condition," are redefined in terms of the concepts
discussed herein.

Objectives

The objectives of this research effort are to:

1. Determine the expected annual maintenance expenditures for
a facility based upon age, size, and the function which occupies the
facility.

2. Define the elements that determine the economy of keeping or
replacing an existing facility.

3. Compare the present value of all future costs of an existing
facility with the present value of all future costs of the replacement
and rehabilitation alternatives.

4. Analyze the economic advantages and disadvantages of keeping
a facility versus replacement or rehabilitation of the facility.

Research Questions

1. What are the expected annual maintenance costs for a facility
on Myrtle Beach AFB based upon its age, size, and functional use?

2. What cost factors are pertinent when considering replacement/
rehabilitation?

3. At what point is there economic advantage to rehabilitation or replacement of a given facility?

CHAPTER II

REGRESSION ANALYSIS

Many base civil engineers with maturity, experience, and technical judgement display an ability to predict, with some degree of accuracy, what their future maintenance expenditures will be. This ability is surely based on an intuitive "feel" for the influence of the numerous variables which affect future maintenance expenditures. However, there is a more explicit method than intuition of relating the major variables which might affect maintenance expenditures. That method is multiple regression analysis.

Multiple regression analysis is a statistical method which relates the value of a dependent variable to the influence of two or more independent variables all acting at the same time. For example, the price at which sugar sells at wholesale may depend upon the production of that season, the carryover from the previous season, the general level of prices, and the prosperity of consumers. Since all conditions indicated above (which are assumed to affect the final price) are constantly changing, only the total result of all the factors in the existing situation can be measured at any given time.

Maintenance expenditures for a given facility might be considered analogous to the price of sugar in the example given above; that is, the dependent variable. And such facility characteristics as the size, age, condition, type of construction, functional use, etc., would be independent variables which, in combination, affect the overall maintenance expenditures on a facility.

The foregoing suggests consideration of a multivariable regression analysis using annual maintenance expenditures for a given facility as the dependent variable and as many independent variables as the data source can credibly provide.

In the situation indicated where a dependent variable is influenced by two or more independent variables, the relationship is represented mathematically by the equation:

$$(2.1) \qquad Y = B_0 + B_1 X_1 + B_2 X_2 + \cdots + B_{p-1} X_{p-1}$$

Where: Y = the dependent variable

$X_1, X_2 \cdots X_i \cdots X_{p-1}$ = the independent variables

$B_0, B_1, B_2 \cdots B_{p-1}$ = net regression coefficients

The right hand side of the above equation is a hyperplane, termed the "regression plane," in "p" dimensional space, and is "best fitted" to the data by the method of least squares. The regression plane describes the average relationship existing between Y (the dependent variable) and the X_i's (the independent variables) and provides a method of estimating the dependent variable when values of the

independent variables are inserted into the equation.

The least squares method is a curve fitting technique which, based

on explicit assumptions, insures that a hyperplane fitted to a set of

data is the "best fit" within the limits of the assumptions. For an in-

depth development of the least squares method, see (20) and (23).

The following model is used to accomplish a regression analysis

on a population of 74 facilities at Myrtle Beach Air Force Base,

South Carolina:

(2. 2) $\qquad Y = b_o + b_1 X_1 + b_2 X_2 + b_3 X_3$

Where:

Y = the total dollar amount of maintenance accomplished
on a given facility in FY 73.

X_1 = the age of the facility in years.
X_2 = the size of the facility in square feet.
X_3 = the functional use of the facility where functional
use is numerically defined as follows:
1 = maintenance facility
2 = administrative facility
3 = warehouse or covered storage
4 = airmen barracks
5 = training facilities
6 = personnel support facility
7 = bachelor officer quarters
8 = communications, electronics, NAVAID facilities
9 = recreation facility
10 = operational facility

The weighting factors for functional use (X_3) are selected based on the

authors' experience and are felt to be representative of present

functional priorities used in the application of maintenance resources.

The data upon which the regression analysis is based are taken

from two automated reports from Myrtle Beach AFB, South Carolina.

Annual maintenance costs by facility for FY 73 are taken from the
Base Engineer Automated Management System (BEAMS) Cost Account
by Facility (CAF) Report. Values for the independent variables (age,
size, and use) are taken from the HAF-PRE(SA) 7115 Report, USAF
Real Property Inventory Detail List, dated 30 June 1973. A consoli-
dation of the data used in the regression analysis is contained in Table
2-1. All facilities having an area less than 2,000 square feet, which
includes all military family housing units, are excluded from the
analysis since it is felt that they are not representative of the population
of interest.

Using a computer program developed by James (23) which provides
a solution by matrix manipulation, the following multiple regression
equation is obtained:

(2. 3) $Y_c = -3248. 36 + 165. 32 X_1 + .507 X_2 + 384. 23 X_3$

$$b_o = -3248. 36$$
$$b_1 = 165. 32$$
$$b_2 = .507$$
$$b_3 = 384. 23$$

It is important to realize the implications of the b_o term in the
above equation. The fact that b_o is negative is merely a result of
the method (least squares) used in "forcing" the best relationship
between the dependent and independent variables. The fact that b_c is
negative points out an interesting characteristic of the data used.
Given a particular facility of specified size and function, the relation-
ship of maintenance expenditures over time is minimal in the early

TABLE 2-1

DATA FOR REGRESSION ANALYSIS,
FACILITY MAINTENANCE
EXPENDITURES, FY 73
MYRTLE BEACH AFB

Bldg No.	Maint Cost ($) Y	Bldg Age (Yrs)(X_1)	Bldg Size (S.F.)(X_2)	Functional Use (X_3)	
104	$10,645	18	17,652	2	(Hq. A. B. Gp)
105	1,854	17	2,177	2	(Consol Bse Per)
106	10,325	18	12,777	2	(Consol Bse Per)
108	7,546	18	4,642	8	(Comm Ctr)
110	1,124	6	3,400	8	(NAVAID Shp)
112	7,004	15	7,080	6	(Chapel)
113	387	12	4,345	6	(Hospital Whse)
115	5,772	14	8,742	7	(Off Qtrs)
116	4,051	17	6,185	8	(Theater)
117	12,396	17	19,467	11	(Rec Ctr)
119	3,834	17	11,767	6	(Bse Exchange)
120	15,202	17	14,707	9	(NCO Club)
124	13,906	17	14,248	9	(Off Club)
126	11,616	15	23,570	7	(Off Qtrs)
127	4,946	13	10,075	7	(Off Qtrs)
132	4,159	12	10,200	9	(Bowling Alley)
154	834	9	3,750	6	(Kindergarten)
155	2,884	14	4,542	6	(Child Care Ctr)
162	824	17	5,644	6	(Exch Store)
200	822	15	2,961	6	(Exch Sta)
212	1,588	17	5,041	2	(Hq A. B. Gp)
213	918	11	2,030	3	(Whse)
215	3,514	17	3,342	3	(Cold Storage)
219	5,297	17	5,911	2	(BCE Admir.
220	4,231	17	13,153	1	(BCE Shops)
223	2,189	14	4,800	3	(Whse)
228	13,339	14	11,150	6	(Commissary)
231	2,083	17	2,891	9	(Library)
232	1,563	17	2,891	6	(Exch Outlet)
233	1,750	17	2,891	6	(Exch Outlet)
234	2,687	17	2,891	6	(Cloth Sales)
241	13,612	14	25,229	4	(Am Dorm)
242	10,150	15	24,250	4	(Am Dorm)
243	4,874	15	24,000	4	(Am Dorm)
244	14,282	17	25,016	4	(Am Dorm)
245	21,934	17	14,111	6	(Dining Hall)

TABLE 2-1--CONTINUED

Bldg No.	Maint Cost ($) Y	Bldg Age (Yrs)(X_1)	Bldg Size (S.F.)(X_2)	Functional Use (X_3)	
246	$10,139	17	24,626	4	(Am Dorm)
247	15,505	17	24,626	4	(Am Dorm)
248	14,604	17	24,626	4	(Am Dorm)
249	11,231	17	24,626	4	(Am Dorm)
250	18,077	17	12,185	9	(Rec Ctr)
251	33,820	17	24,626	4	(Am Dorm)
252	6,730	17	24,626	2	(Hq A. B. Gp)
255	1,963	11	7,003	9	(Rec Wk Shop)
256	8,258	3	21,483	9	(Gym)
320	2,317	14	5,000	1	(Age Shop)
324	6,800	17	30,312	1	(Acft Maint Shop)
326	1,785	17	6,726	1	(Parachute Shop)
327	766	7	7,200	1	(Avionics Shop)
328	3,780	3	7,282	1	(Acft Fuel Shop)
330	8,337	17	10,715	2	(Wg Maint Cont)
334	6,376	17	4,967	6	(Dental Clinic)
336	2,870	17	12,370	5	(Fld Training Fac)
341	5,061	7	11,340	5	(Fld Training Fac)
343	3,454	16	5,576	2	(Wg Hqtrs)
345	1,400	17	8,373	2	(Sq Ops)
346	2,726	17	8,373	2	(Sq Ops)
347	3,605	17	8,373	2	(Sq Ops)
348	4,327	17	6,235	5	(Intll Train)
349	7,534	17	8,373	2	(Sq Ops)
360	12,205	17	18,344	2	(Fire Sta)
362	8,158	17	10,399	10	(Base Ops)
405	2,367	10	3,750	9	(Golf Fac)
406	4,129	10	2,500	9	(Golf Fac)
448	2,698	12	4,584	2	(S. P. Ops)
454	68	3	2,352	2	(S. P. Ops)
475	18	30	3,775	3	(BCE Stge Fac)
500	1,260	17	2,675	2	(Admin Off)
512	2,512	7	2,062	2	(Auto Admin)
514	11,964	15	19,818	1	(Auto Maint Shop)
516	3,144	13	2,680	1	(Veh Refuel Shop)
581	1,196	1	3,774	1	(Ammo Maint Shop)
587	72	1	5,000	3	(Stg Spare Inert)
588	105	1	5,000	3	(Stg Spare Inert)

years. That is to say, any combination of independent variable values which result in a negative value for the dependent variable are interpreted as zero maintenance cost for that year.

The use of the regression equation for estimation of maintenance costs, Y_c, is now illustrated. Assume the maintenance expenditure for a facility from the population is to be estimated. Assume that the facility is a ten year old, 20,000 square foot airmen dormitory. Substituting $X_1 = 10$, $X_2 = 20,000$ square feet, and $X_3 = 4$ yields the following estimated annual expenditure for maintenance:

$$Y_c = -3248.36 + 165.32 (10) + .507 (20,000) + 384.23 (4)$$

$$Y_c = -3248.36 + 1653.20 + 10,140 + 1392.92$$

$$Y_c = \$9,937.76$$

Now consider the meaning of the net regression coefficients, b_0, b_1, b_2, and b_3. The constant, b_0, is the Y intercept or the value of Y_c when X_1, X_2, and X_3 are all equal to zero. The b_1 coefficient measures the change in Y_c per unit change in X_1 when X_2 and X_3 are held fixed. The coefficients b_2 and b_3 are similarly interpreted.

For example, the b_1 value of 165.32 indicates that if a facility is one year older than another of the same size and functional use, then the estimated annual maintenance expenditure on the older facility exceeds that of the younger facility by $165.32.

Standard Error of Estimate

Having determined the regression equation for purposes of

prediction of the dependent variable based on values of the independent variables, it is appropriate to determine the degree of accuracy of the regression model. The standard error of estimate, $S_{y.123}$, provides a measure of the dispersion or scatter around the regression hyperplane and is used as an indicator of the error of estimation. The standard error measures the closeness of estimates derived from the regression equation to the actual observed values of Y. (20:515) Mathematically, the standard error of estimate is defined as:

$$S_{y.123} = \sqrt{\frac{\sum (Y - Y_c)^2}{n-p}}$$

Where: Y = the observed value of the dependent variable

Y_c = the estimated value of the dependent variable based on the regression equation

n = number of observations

p = number of net coefficients

Based on the data, a standard error of estimate of $2,688 is obtained. Hence, assuming a normal distribution of "Y" values around the regression hyperplane, about 2/3 (actually 68.26%) of the points are within one $S_{y.123}$ or $2,688 of the Y_c values computed from the regression equation. Prediction intervals for individual estimates of Y_c are obtained using the following formula:

$$Y_c \pm (Z)(S_{y.123})$$

Where Z is the specified number of sample standard deviations from the mean.

In the previous example using the regression equation, maintenance costs were predicted to be $9,937. A prediction interval of $\pm$ one sample standard deviation is given by:

$$Y_c \pm 1 (S_{y.123}) = \$9,937 \pm 1 (2688)$$

$$= \$7,249 \text{ to } \$12,625$$

It can now be said that the expected annual maintenance expenditure on a ten year old, 20,000 square foot airmen dormitory is between $7,249 and $12,625, 68.26% of the time, and the best estimate of that value is $9,937.

The variance from the regression equation is quite large. This is not totally unexpected since there are certainly more factors which influence facility maintenance cost than age, size, and functional use. For instance, a similar regression analysis was accomplished by the Battelle Memorial Institute. (39) They found that independent variables based on exterior wall material and roof construction material helped to reduce the variance of their regression equation.

Another factor which might account for the wide variance is the amount of cyclic maintenance which may be present in the data. Routine, day-to-day maintenance of a facility might be expected to rise over time at a relatively constant rate. However, maintenance actions such as interior or exterior painting, roof replacement, and siding replacement are cyclic in nature and are in fact a one-time correction of deterioration which has occurred over time spans of three to twenty years. Although cyclic maintenance corrects

accumulated deterioration, its cost is reflected in the fiscal year in which the work is accomplished. In comparison to routine maintenance, cyclic maintenance could be several times greater. To lessen the effects of cyclic maintenance costs on the regression relationships, total cyclic costs should be prorated, over the number of years since this type of maintenance was last accomplished. This method would "smooth" the lump sum costs over the period which its accomplishment is directed at correcting.

A case in point is building 251, airmen dormitory, shown in Table 2-1. Of eight dormitories which are approximately the same size and age, building 251 had $15,743 more maintenance accomplished on it in FY 73 than any other dormitory. This seems to indicate that some major item of cyclic maintenance was accomplished on building 251 in FY 73. Cyclic maintenance costs of this nature could help explain the large variance in the results of the regression analysis.

Multiple Coefficient of Determination

The multiple coefficient of determination $R^2_{y.123}$ provides a measure of the proportion of variance in the dependent variable, Y, which is explained by the regression equation. If the total variance in Y, S^2_y, is defined as the error variance around the regression plane, the coefficient of determination, $R^2_{y.123}$, is:

$$R^2_{y.123} = 1 - \frac{S^2_{y.123}}{S^2_y} = 1 - \frac{\text{Unexplained Variance}}{\text{Total Variance}}$$

Hence, $R^2_{y.123}$ measures the proportionate reduction in error variance if the regression equation is used rather than the mean of Y's to estimate the dependent variable, Y. (20:518)

The multiple coefficient of determination, $R^2_{y.123}$, is 0.539. Thus, approximately 54% of the variance in FY 73 maintenance costs for facilities is "explained" by the regression equation.

Statistical Test of Usefulness of Regression Model

One statistical test is used to determine the usefulness of the regression model. The test provides an evaluation of the "overall" regression equation. This test is accomplished using the "F-distribution" which is based on variance ratios. The results indicate that the probability that all regression coefficients are equal to zero is less than .01. Therefore, overall, the combination of the three variables used to establish the net regression coefficients do affect annual maintenance costs.

Conclusions

The results of the regression analysis indicate that age, size, and functional use are indeed related to annual facility maintenance costs.

On the other hand, the large variance in the regression prediction indicates that additional factors should be considered in the regression analysis. Inclusion of additional factors such as type of construction, amount of BEMAR, and condition of the facility may well reduce the

variance in the regression prediction equation. In addition, some means of identifying and "smoothing" cyclic maintenance expenditures would help to reduce the variance.

The reader is cautioned that the regression equation developed herein is only applicable to the population on which it is based. The fact that the analysis is limited to one Air Force base implicitly assumes that factors such as climatic conditions are constant and do not significantly affect the annual maintenance costs from year to year.

It should also be remembered that the data upon which the regression analysis is based are "cross-sectional" in nature. That is, the data reflect the way in which the value of the dependent variable, Y, changes per unit difference in the independent variables. "Time-series" data, on the other hand, pertain to the way that the dependent variable changes over time as the independent variables change over time. For this reason, it is not appropriate to extend the prediction capability of the regression equation beyond the maximum values of the independent variable. The regression equation developed is only applicable to facilities on Myrtle Beach AFB, for a maximum age of 20 years, a maximum size of app. ximately 30,000 square feet, and for the functional uses used in the development of the regression equation.

CHAPTER III

RELEVANT COSTS IN THE REPLACEMENT
CONSIDERATION

Introduction

Although it is essential that both costs and benefits be considered
in a decision involving a choice between alternatives, the model to be
developed herein considers only costs. Certain benefits to be derived
from one alternative can be represented as a cost in a competing
alternative. Relevant costs are those initial and future costs which
would be affected in the selection of a given alternative.

The economic life of a facility, as defined in chapter I, is a
function of the magnitude of the relevant costs of all alternatives and
when they occur. For this reason, a facility does not have an inherent
economic life. Economic life can only be determined by a periodic
economic comparison of the alternatives. It is this periodic evalua-
tion that determines whether or not a facility should be replaced. In
addition to economic life, the life of a facility can also be viewed from
a physical and functional standpoint. Since the determination of a
facility's economic life takes into account both physical and functional
life costs, it is important that these views of facility life also be defined.

Physical life refers to the period of time that the facility will be available before deterioration and decay render it useless. Physical life recognizes the inexorable effect of the elements and continued use on the materials from which the facility is formed. Even though periodic maintenance can prolong the physical life of a facility, eventually the cost of forestalling the deterioration ceases to be cost-effective.

Functional life refers to the period of time the facility is required to support the function which operates from within its boundaries. In many instances, because of changing technology or reorganization, the function which a facility was designed to support may no longer be required. For example, a maintenance facility designed and constructed to support a specific type aircraft reaches the end of its functional life when the aircraft is no longer required. Since the function which the facility supports is no longer required, the facility is likewise no longer required. In most instances, a facility reaches the end of its functional life long before it reaches the end of its physical life.

The major incentive for replacement or rehabilitation of a facility should be the elimination of facility conditions which impair the effectiveness and/or efficiency of the organization which operates from the facility. Figure 3-1 shows the relevant costs in a replacement consideration and their determinants.
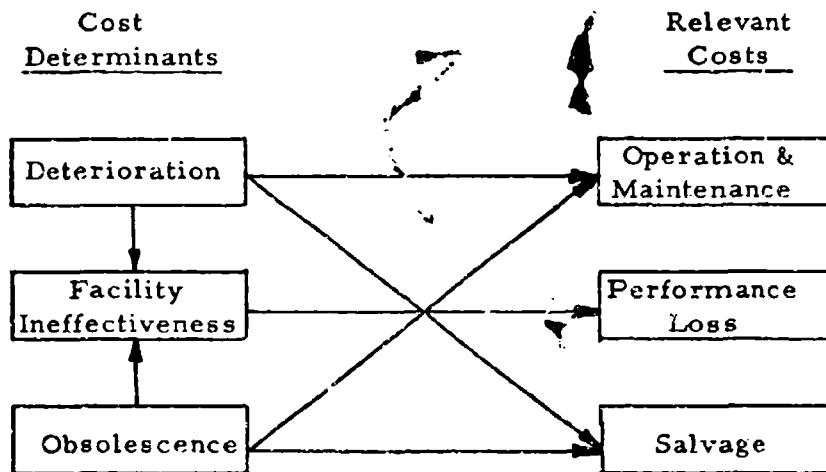
Figure 3-1. Determinants of Relevant Costs

Although the magnitudes of all relevant costs are essential to analytical economic assessments, it is equally important that the determinants of these costs and their interrelationships be understood. This chapter describes the cost determinants and their singular and combined effects on the magnitude of the relevant costs.

A facility should be viewed as a system with many interrelated subsystems or components, such as the electrical system, structural system, mechanical systems, etc. Deterioration and obsolescence affect each of the facility's components as well as the facility as a whole. In addition, the combined effect of obsolescence and deterioration can result in what the authors term "facility ineffectiveness," i.e., a degradation of the working environment provided by the facility. The extent to which deterioration and obsolescence are forestalled by maintenance during the facility's existence determines its salvage value.

The investment required in the rehabilitation or replacement alternatives is also a relevant cost. The investment cost is a function of the design parameters of the replacement facility or the scope of the rehabilitation project. Since investment cost is not a function of deterioration and obsolescence, it is not reflected in Figure 3-1; however, it is specifically addressed herein.

Deterioration

Deterioration is defined as the physical aging of the facility and its components. This phenomenon produces a decline in operating performance of the facility as compared with that of identical new replacements and manifests itself in increasing maintenance costs and a lower quantity or quality of performance. (30:112) What actually happens is that from the day a facility is constructed, its components begin to deteriorate in relation to their original capability. This process is gradual in most cases, but by the end of any substantial period deterioration is noticeable. (19:48)

> The typical facility as a system exhibits a continuous
> process of deterioration over time, a complex process
> in which a large number of interrelated performance
> characteristics change to produce overall reduced
> system effectiveness. (11:1)

There are many variables which influence the magnitude and rate of deterioration. These include design variables such as the type of construction, the size of the facility, and the age of the facility or component; environmental variables such as the component loading

(actual load versus the design load) and climatic conditions; and policy variables which describe the operations and maintenance spending policies of the organization responsible for operation and maintenance of the facility. This listing of variables should not be considered exhaustive. These variables merely represent some of the major determinants of the rate of deterioration experienced by a facility and, therefore, are direct determinants of the magnitude of expected annual maintenance costs of a facility over time. (11:11)

The physical deterioration a facility undergoes during any given period of time is not easily determined. Construction materials and the facility systems which they comprise deteriorate over time. The extent of deterioration in many instances may not be observable or economically correctable; for example, the internal corrosion of the pipes in a heating system. The piping may appear excellent from the exterior, but the entire system could collapse upon reaching the point where the system has been completely eroded from the interior. Similarly, the complete deterioration and failure of a facility's electrical or roof system may, by its extensiveness, prove too costly to replace. Therefore, in many cases reversal of these forms of deterioration can only be accomplished by replacement of the facility or the components affected. Repair by replacement is an extreme form of maintenance. However, most forms of deterioration can be corrected by timely maintenance.

The purpose of maintenance is to correct and forestall physical deterioration. The condition of a facility is a function of the amount of deterioration and the funds expended to combat deterioration. Condition is not only a measure of physical adequacy, but is also a measure of functional adequacy.

A facility's condition varies over its life, primarily as a result of the amount of maintenance funds available. Since the maintenance requirements for a facility quite often exceed the funds available, a "level of maintenance" evolves for each facility based on its mission and the resources available. Therefore, the "level of maintenance" can be defined as the exte$\cdots$ to which maintenance services are applied to a facility. Extreme "levels of maintenance" could range from accomplishment of all maintenance requirements to no maintenance at all. However, it must be realized that due to resource and policy constraints, it is usually not possible to satisfy all the maintenance requirements of a facility and the level of maintenance falls somewhere in between the extreme policies mentioned. The backlog of maintenance that results is specifically discussed in chapter V. However, the fact that there are outstanding maintenance requirements for a facility indicates a steadily worsening condition of the facility over time until these requirements and their cumulative effects are corrected.

As indicated earlier, deterioration partially manifests itself in increasing operation and maintenance costs. It is generally agreed

that the rate of deterioration of a facility is directly related to its age.
Maintenance costs are those costs attributable directly to the magni-
tude and rate of deterioration of a facility.   Therefore, it would
appear that maintenance costs are directly related to the age of a
facility.

Following are the results of three studies which relate the dollar
cost of facility maintenance to the age of the facility.

The "U-Shaped Curve Theory" (see figure 3-2) suggests that
maintenance costs typically conform to a "U-shaped" pattern.   These
costs are high during the first years of a facility's life due to correc-
tions of unforeseen deficiencies embodied in the structure, diminish
during the middle years, only to increase again during later stages due
to the increasing failure rate of components.   (1:13)
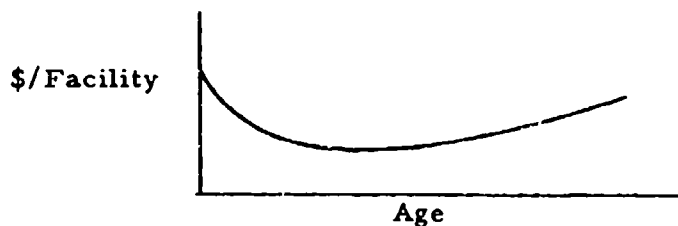
Figure 3-2.   U-Shaped Curve Theory
(Annual maintenance costs of a facility over its
lifetime.)

The "Increasing Cost" hypothesis (see figure 3-3) suggests that
maintenance costs increase with the age of the structure.   This is due
to the increasing difficulty in obtaining and installing replacement

parts and the higher incidence of component failure due to prolonged

usage.   (1:5)
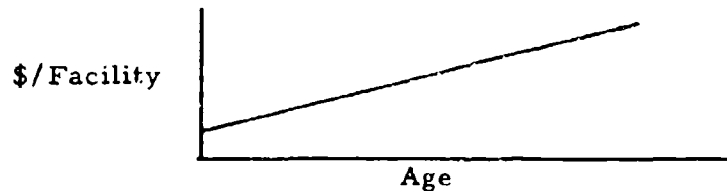
Figure 3-3. Increasing Cost (Annual
maintenance costs of a facility over its life-
time.)

The "Power Model of Age Effect" (see figure 3-4) demonstrates

that maintenance costs do increase with time, but at a decreasing rate.

The largest increase in maintenance costs accures during the early

years of a facility's life due to correction of unforeseen deficiencies

in the original construction.   Subsequent increases in maintenance

cost throughout the life of the facility were felt to be attributable to

excessive "wear and tear" through prolonged usage.   (1:5)
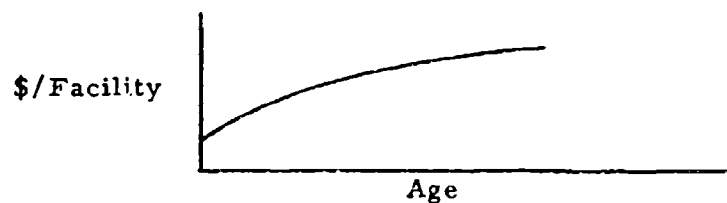
Figure 3-4. Power Model of Age Effect
(Annual maintenance costs of a facility over its
lifetime.)

The above maintenance theories indicate the conflicting nature of

available data. In general, the studies all reflect an increase in

maintenance costs over time.   The authors feel that a typical mainte-

nance cost trend would be a combination of the previous theories as

shown in figure 3-5.   Maintenance costs are minimal in the early years

due to the advanced techniques of design and improved construction

materials in use today.   They tend to increase at an increasing rate

through the middle years due to increasing component deterioration

and failure.   Then, towards the end of a facility's life, the costs

increase at a decreasing rate and approach a constant annual cost.

This is due to several factors: the availability of maintenance resources

to apply against requirements, the maintenance policy employed, and

the decreasing incidence of component failure.
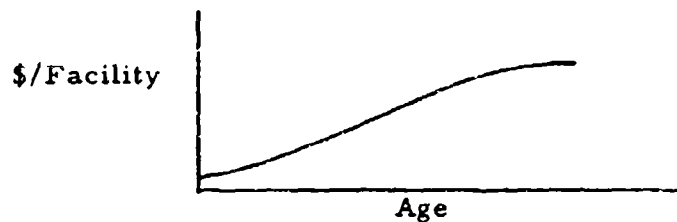
Figure 3-5.   Annual Maintenance
Costs Over the Facility's Lifetime

The maintenance costs included in the foregoing discussion and

curves represent a combination of (1) preventive type maintenance,

which is primarily designed to restore components which have deterior-

ated due to wear and tear; (2) cyclical type maintenance which is

required at specific intervals throughout the life of a facility to fore-

stall deterioration; (3) emergency maintenance which is required

immediately to correct the failure of a component; and (4) repair, which involves the restoration of components which have failed or are failing due to sustained deterioration.

Generally speaking, when maintenance (either preventive or cyclical) is not accomplished over a period of time, an increasing number of emergency and/or repair projects are required. It is generally agreed that the more money that is spent on preventive maintenance, the less that is spent on emergencies and repairs. (25:4) This is especially true when preventive maintenance anticipates component failure; for example, replacing roofs in dry weather or resurfacing roads before they become so damaged that subbase repairs are required.

Figures 3-6 and 3-7 graphically portray a comparison of the total cumulative costs to provide facility support for a function for "M" years. Figure 3-6 shows the cumulative costs of preventive and cyclic maintenance for a facility used continuously over a period of "M" years. Figure 3-7, on the other hand, shows the total cumulative costs over the same period when the facility requirement is fulfilled by an original facility, and a replacement facility constructed after "N" years. These illustrations do not consider the time value of money nor the other relevant costs to be discussed later in this chapter. They merely indicate that by using the maintenance cost trend previously discussed (figure 3-5), the total cumulative cost of providing facility support can be less with the replacement method. The

CUMULATIVE COSTS OVER LIFETIME
OF A FACILITY (24:5)
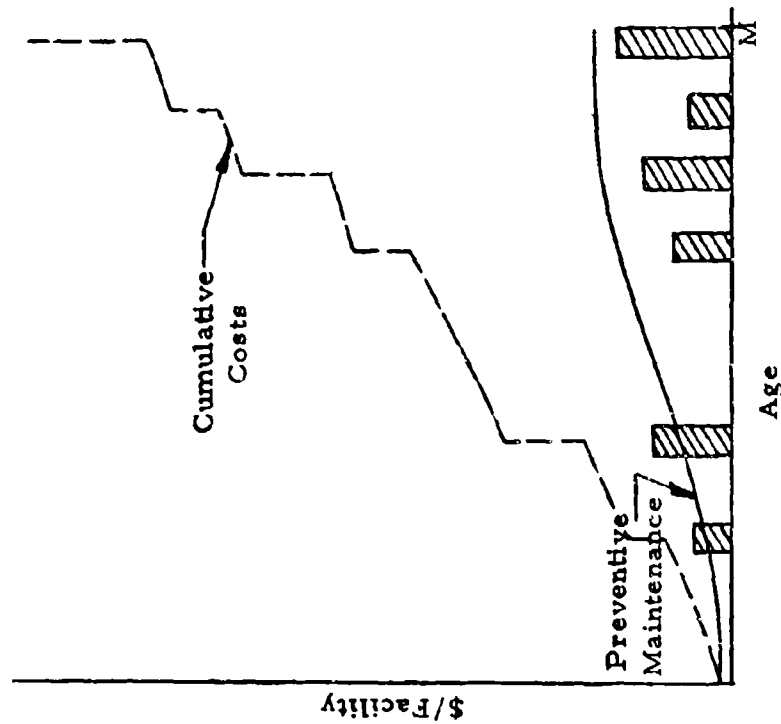
Figure 3-6.--Without Replacement
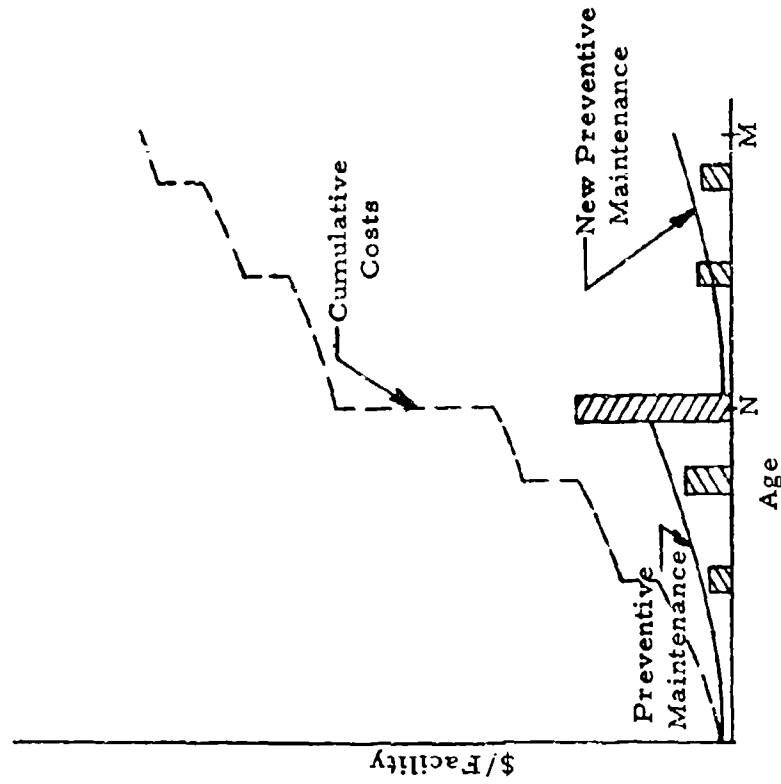
Figure 3-7.--With Replacement

Cyclical Maintenance and Repair Cost

Facility Replacement Cost

replacement facility, as shown in figure 3-7, reduces both the magnitude and frequency of routine and cyclic maintenance, thereby reducing the total cumulative cost over "M" years.

As maintenance costs increase over the physical life of a facility, so to can operation costs. The deterioration of utility systems within a facility can reduce their efficiency and/or their capacity. Corrosion of water and heating lines, deterioration of insulation on electrical wires, or on air conditioning piping are all examples of deterioration which can result in rising operation costs. Facility deterioration can also affect operation costs; for example, as exterior surfaces deteriorate and the building insulation is affected by the elements, both heating and air conditioning costs could increase.

Operation costs are not of the same magnitude as maintenance costs on a single facility basis. However, the operation costs over the life of a facility are considered significant, and are included as a relevant cost in the replacement decision.

Obsolescence

Another important factor in the determination and analysis of replacement/rehabilitation costs is the obsolescence of a facility and its components. As Professor Joel Dean of Columbia University's Graduate School of Business indicates:

> The most important replacement determinant is the
> obsolescence rate.... Obsolescence is pervasive and
> strategic in the American economy in determining the
> level of business activity and it should be appreciated

>for its capricious and volitile self.   Physical deteri-
>oration is rarely a deciding factor in replacement of
>durable goods.   (12:149)

Professor Dean's remarks are directed toward equipment replace-
ment and reflect an awareness on the part of private industry of the
importance of obsolescence in replacement considerations.   Private
industry's consideration of this factor is undoubtedly due to the profit
motive and the requirement to remain competitive.   Since the profit
incentive and competition do not exist within the Department of Defense,
the concept of obsolescence is seldom adequately addressed.   Since
facilities are a form of "durable goods," the authors feel that the
concept of obsolescence should be logically extended to facility replace-
ment decisions within the Department of Defense.

This research effort will view obsolescence in two ways--tech-
nologically and functionally.   Technological obsolescence is defined
as the degree to which a facility or its components have been "out-
dated" by technological advances.   Technological advances provide
stronger, more durable materials; more efficient parts, processes,
and subsystems; and improved maintainability.   Functional obsoles-
cence is defined as the degree to which a facility fails to provide an
adequate working environment for the assigned function.   Functional
obsolescence occurs as a result of new operating policies and proce-
dures, new organizational equipment, reorganizations, and changes in
functional layout.

Technological obsolescence is manifest in the difference in operation and maintenance costs of the existing facility when compared to a new technologically superior facility. Functional obsolescence, on the other hand, is manifest in the difference in the levels of performance attainable in the existing facility as compared to a new "functionally oriented" facility.

Confusion often exists regarding the relationship between the deterioration of a facility and its state of obsolescence when the two are lumped together under the term "age." The normal assumption being that an "old" facility is automatically worn out and obsolete. There is no rigid relationship among the three notions of age, deterioration, and obsolescence. Deterioration can be arrested through a suitable program of maintenance. Obsolescence comes about as an inevitable consequence of the passage of time. That is to say, the occurrence of one does not necessarily precipitate the occurrence of the others. Technological obsolescence depends strictly on the rate of technical progress. (27:44)

Generally speaking, functional obsolescence is an instantaneous happening prompted by changing mission requirements. When current operating conditions change, an older facility occasionally lacks the functional character to meet new requirements. That is to say, the existing facility is not adaptable to new functional requirements unless building modification or rehabilitation is undertaken.

Just how important is the obsolescence factor? Certainly if the benefits to be derived from an up-to-date facility outweigh the cost to provide it, we should strive for a replacement/rehabilitation of the existing facility. The cost of technological advancement is often quite high, as experienced by the Department of Defense in acquiring weapons systems. Our goals for performance to be obtained from a facility must be realistic, and we must be willing to make practical trade-offs between operating requirements and engineering design. Obsolescence does not present as great a problem in facility replacement as it does in weapon system acquisition. However, it is a relevant cost that must be addressed in replacement considerations. With the present age of the Air Force facility plant, there appears to be a substantial savings available should obsolescence be considered.

Facility Ineffectiveness

Deterioration and obsolescence are also considered determinants of facility ineffectiveness. That is to say, the ineffectiveness of a facility is a measure of the amount of deterioration and obsolescence which have not been counteracted by maintenance, repair, or replacement throughout the facility's existence.

There is yet another relevant cost which must be addressed in a replacement decision. This cost is caused by the facility's ineffectiveness in providing a suitable environment for the assigned function to efficiently carry out its assigned mission.

> Each component of a facility can be expected to affect
> the mission of the facility depending on the state that
> the component is in; the states of the component can
> be expected to have different impacts on the different
> missions for which a facility may be used. ... In many
> cases, the degradation of the facility mission will be
> very closely correlated with the effectiveness of the
> facility as a whole, e. g. , the electrical power distri-
> bution component in a missile launch facility, while in
> other cases there may not be a clear-cut relationship
> (e. g. , with the roof component of a warehouse facility.)
> (11:17)

As the environment provided by the facility worsens, there is an

attendant loss in the performance of the assigned function. Perform-

ance, as previously defined, can be a measure of the function's

effectiveness, efficiency, or both. The cost itself is manifest in one

of two ways. Either the required output or service will be diminished

or more resources will be required to provide the same level of output

or service.

The determination of the performance loss in quantitative terms is

extremely difficult within the Air Force. Performance measurement

in the private sector, however, is possible through the use of the

profit and loss statement. The profit and loss statement is based on a

performance accounting system whose objective is measuring organi-

zational effecti'eness and efficiency. The difficulty of output measure-

ment in the Department of Defense is a recognized obstacle as the

following passage indicates:

> Economy and efficiency are sometimes difficult to define,
> even more difficult to measure. Private industry can
> gauge its success from the financial statement. In
> Government the system of goals and incentives is

different. With very few exceptions the managers of
Government agencies have no general indicator of the
effectiveness of their choices or the efficiency of their
performance comparable to the information in the profit
and loss statement. (34:179)

When the environment is one of a service-oriented organization,
such as the Air Force, the problem of performance measurement
becomes quite difficult. In order to determine the loss in perform-
ance and thereby the ineffectiveness of the facility, one must be able
to measure the output provided by the function and the cost to provide
that output, against established standards.

At present, the effectiveness of an Air Force organization is
measured by operational readiness or general inspections. These
inspections represent a subjective evaluation of an organization's
performance against established regulations and procedures. Except
for industrially funded operations, measurement of organizational
efficiency is nonexistent in the Air Force.

The Air Force is now testing the Resource Management System
(RMS), a part of which defines output measures and performance
standards for some Air Force functions. The thrust of this system is
to provide a performance-type budget. That is to say, establish the
various output measures and their appropriate standards and in this
way provide a measure of performance. In addition, the collection of
costs is oriented toward specific organizational outputs which allows
for the measurement of organizational efficiency. The RMS system,
as presented here, is grossly oversimplified; however, the point is

that the measurement of organizational performance may not be far off.
The RMS concept provides a quantitative method of measuring a facil-
ity's effectiveness in terms of dollar costs. Even without the tools to
measure it, this loss in performance is felt to be a significant cost
and definitely should be considered, whether quantitatively or qualita-
tively, in every replacement decision.

The relative importance of deterioration and obsolescence in
determining facility ineffectiveness and resulting performance loss
varies widely from case to case. Nevertheless, due to continued use
and the passage of time, a "gap" develops between the operating
performance of the existing facility and the best possible performance
obtainable by an alternative method. This "gap," termed "operating
inferiority," by George C. Terborgh, is defined as, "the amount by
which the machine [facility] is inferior, operationally, to its challen-
ger." (42:62)

Figure 3-8 is a graphical representation of the total advantage of
a new facility based upon the combined effects of deterioration and
obsolescence on output over time.
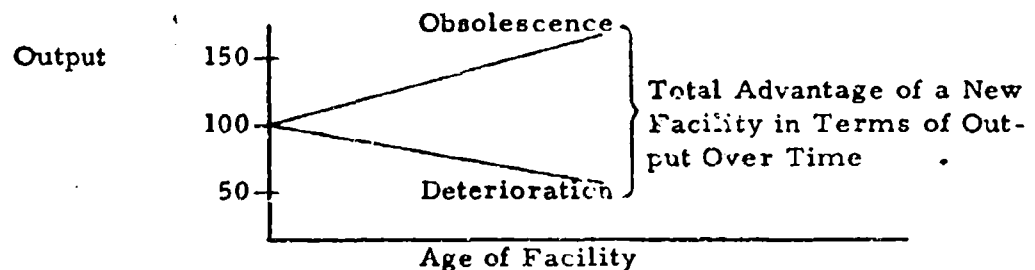
Figure 3-8. Combined Effect of Obsolescence
and Deterioration on Output (19:50)

Obsolescence is shown in figure 3-8 as an increasing function over time, indicating a continual increase in available output from a new facility as compared to the existing facility. The extent of this increase is a function of technological and functional improvements which could be made to the facility.

Deterioration is shown as the cause of a continual decrease in output as compared to the facility when new. The extent of this decrease is primarily a function of the amount of maintenance which is performed on the facility.

Additional interpretation of figure 3-8 indicates that in order to maintain the initial level of output (figure 3-8 shows initial output as 100 units), more and more resources are required to offset the effects of deterioration. At the same time, there is increased capacity available from the use of new products, processes, or procedures.

An Air Force function can compensate for reduced operating efficiency by increasing its requirements for manpower above that which it has required in the past. If the function cannot compensate for this loss in efficiency caused by facility ineffectiveness, then its reduced output or service affects the performance of other functions through its backlog or reduced quality of service. In the final analysis, national security could be degraded from its anticipated level. That is to say, if national security is defined in terms of certain perform-ance levels, the funds required in associated investment and O&M programs to provide these levels of performance must be provided.

Without these funds, at some point their absence manifests itself in a reduction of national security.

The working environment provided by the facility can have a significant effect on the worker and his performance. Much research has been done and many advances have been made in the area of human engineering. This technique primarily involves the marriage of man and machine systems. This is accomplished by considering the physiological and psychological limitations of human beings when designing machines and tools A prime example of the application of human engineering concepts is the design and development of the Apollo space capsule. The design considers the whole man-machine system and integrates human capabilities and limitations with the physical equipment.

The basic assumption of human engineering philosophy is that man should be considered one of the major components of a complex man-machine system rather than merely a user of the system once it is developed. It denies that system development is purely an engineering problem, but that psychological and social problems must also be considered.

The natural extension of the human engineering concept to the marriage of the worker, the group or the organization, and their working environment is needed if true effectiveness and efficiency of operations is to be achieved. This applies to private and public workplaces alike. Only within the past decade has extensive research

been undertaken to link the physiological and psychological limitations and desires of the worker to the design of his working environment in an attempt to achieve efficiency of operations.

One example of such research is the Architectural Psychology Program at the University of Utah under the leadership of Professor Calvin W. Taylor. This graduate level program blends the architect who designs environments for people with the psychologist who studies the reaction of people to their environments. The purpose of the program is to study the reaction of people to existing environments as a valuable feedback toward greater understanding and, to provide information toward designing new and better environments. This allows measurement of the performance of buildings with man as the measure.

The Construction Engineering Research Laboratory (CERL), a division of the U.S. Army Corps of Engineers, was established in 1968 and has as its goal to improve the effectiveness and value of military and other Government facilities without undue cost. Their Habitability and Architecture Program, established in 1972, has just begun to conduct extensive research into the physical, social, and psychological needs of military personnel as related to the design of military facilities. One of their overall objectives is to improve performance through the design of reasonably priced environments which contribute to an effective military force.

The field of environmental design based on human factors is wide open and in its infant stages. Much is yet to be learned and much needs to be learned to improve operating efficiency in the public and private sectors. The important factor is that the interest and concern in the concept of application of human factors to the working environment is growing. The incentive is the dollars to be saved in existing and future facilities by increasing the workers' productivity. This is done by ensuring that he has a working environment that he likes.

What are the factors that determine the ineffectiveness of a facility from the workers' viewpoint? As Buffa stated in his book Modern Production Management,

> The working environment, which includes such factors
> as temperature, humidity, noise and light, can produce
> marked effects on productivity, errors, quality levels,
> and employee acceptance, as well as on physiological
> well-being. (8:398)

In addition to the environmental features mentioned above by Buffa, there are many more factors which can be used to demonstrate the effect of the working environment or, the effectiveness of the facility, on the productivity of the worker.

A study presently being conducted by CERL will determine the effect on organizational effectiveness of replacing five existing Corps of Engineers office buildings in Buffalo, New York, with a single facility. The study began with an extensive analysis of the internal organizational communication network. This allows designers of the replacement facility to incorporate a layout which will minimize

distance between those functions which require frequent interaction.
Then a series of psychological surveys were administered to all
workers to determine their perception of the organizational climate,
suitability and availability of office equipment, and the adequacy of the
physical environment (i. e. , heating and cooling, lighting, noise,
layout, available space, etc.). The results of the above mentioned
instruments are being analyzed to determine the major irritants to
personnel performance or satisfaction. Every attempt will be made
to remove the major irritants in the design for the new facility. When
the move to the new facility is completed, the tests will be reaccomp-
lished to determine the overall effect of the new facility on worker
satisfaction and performance. (5)

A research study conducted by Major George E. Secrist, titled
A Total Environmental Approach to Job Performance and Job Satis-
faction (unpublished dissertation), involves 1000 military engineers
and scientists working in the space program. This study addresses the
effects on worker satisfaction and performance of personal-psychological
variables such as age, personality, birthplace, etc.; organizational-
sociological variables such as supervisor-subordinate relationships,
group concepts, authority relationships, promotion policies, etc.; and
physical environment variables. The variables used to measure the
effect of the physical environment on job satisfaction and performance
are (1) human/hardware interfaces, (2) the primary work facilities,
(3) support facilities, (4) noise, (5) ventilation, (6) temperature

control, (7) lighting, (8) privacy, and (9) color. The individuals were questioned regarding (1) their perception of the quality of their physical environment, and (2) how important each of the variables are to their productivity. The results of the study indicate that all of the physical environment variables exhibit a positive correlation to both job satisfaction and job performance. The correlation is much stronger toward job satisfaction than job performance, indicating that as the working environment worsens, the worker becomes more dissatisfied with his job. The coefficient of determination (r^2) between job satisfaction and physical environment is + .35 at the 1% level of significance. The study also concludes that the variables which significantly affect job performance and job satisfaction vary with the type of job. Also, when all three categories of variables are included in a multiple regression analysis, the physical environment variables all contribute positively to the variance of the regression line. This indicates, for the population studied, that the physical environment does in fact affect the workers' satisfaction and performance. (36)

If sufficient information were available to determine the workers' needs in different job categories, facilities could be designed and constructed (or modified in the case of existing facilities) around these needs to ensure worker satisfaction and improve worker performance. (36)

The concept of facility ineffectiveness is, at best, a difficult concept to comprehend and even more difficult to measure. Without output measures and standards of performance for Air Force functions, the evaluation of the cost of facility ineffectiveness is usually a subjective evaluation. It appears that on a facility-by-facility basis the workers' perception of the effect of his working environment on his performance might be the closest to a quantitative evaluation available at present. Even a measure of worker performance entails collection of a tremendous amount of data to achieve creditable results. It is felt, however, that this performance loss due to the ineffectiveness of a facility to provide an adequate working environment is a relevant cost, and its difficulty of determination should not deter its consideration in replacement decisions.

The importance of the quantity and quality of available output or service from a facility cannot be underestimated. As Pierre Masse states in his book Optimal Investment Decisions,

> In a word, one must remember that the value of durable
> goods is, after all, nothing else but the discounted value
> of its future services. (27:45)

Salvage Value

The concept of salvage value recognizes the fact that an aged facility has certain inherent disadvantages associated with its use to provide a good or service as compared to a new facility. It is the recognition of an asset's reduced usefulness that accounts for a

reduction in the value of that asset. If a decision is made to replace an existing facility with a new facility at a different location, an income or expense equivalent to the present value of the existing facility can be realized from its disposal or alternative use to fulfill a less demanding function. The magnitude of a facility's salvage value is a function of the amount of unarrested deterioration and obsolescence which the facility has accumulated over its existence. Terminal salvage value in the private sector is generally determined based on the value of a facility to another user who is willing to purchase the salvaged asset. The determination of salvage value of an Air Force facility based on its sale to a private user has limited applicability since the facility is normally located on controlled Government real estate. For this reason, the terminal salvage value of Air Force facilities is minimal compared to identical facilities in the private sector. In some cases, the salvage value may result in an expense to have the facility razed. Irrespective of whether the salvage value is an income or an expense, it should be included in an economic analysis of the replacement decision.

Investment

For the purposes of this study, an investment is defined as the sum of money employed by the Air Force in providing initial or improved facility support for a specific function. In terms of the replacement decision, the construction of a new facility

and the rehabilitation of an existing facility represent investments and are considered relevant costs. The original investment made in an existing facility which is being considered for replacement has no effect on the replacement decision and, therefore, is an irrelevant cost.

Since the investment cost is usually the largest single cost in a present value analysis of alternatives and since it is incurred immediately allowing its full cost to be considered in the analysis, it usually plays a key role in determining the minimum cost alternative.

In determining the investment required to replace or rehabilitate a facility, every effort should be made in designing the new facility to minimize future recurring costs. That is to say, the best possible working environment should be provided which will allow effective and efficient operation of the function involved while incurring minimum total costs over the anticipated life of the facility. Factors that must be considered in determining the investment are technological advances in facility construction, functional layout, maintenance of facility components, and the incorporation of the workers' desires in the working environment. Consideration of these factors when designing the working environment for a function insures increased benefits over the life of the facility in terms of improved performance.

Conclusions

Theoretically, the objective of each base civil engineer should be

tc minimize the total maintenance expenditures on a facility. This objective is constrained by the requirement that the quantity and quality of output or service provided from the facility meet established standards. Although the base civil engineer has no organizational control over a function's output, his application of maintenance resources can affect the working environment of the facility. If this working environment is allowed to deteriorate, the performance of the organization can be adversely affected causing a reduction in organizational effectiveness and/or efficiency. Therefore, maintenance should be sustained ﹄ he point where its cost is at least equal to the loss in performance which it forestalls. All departures from this policy are heavily penalized by exorbitant total maintenance costs or declines in organizational performance.

The effectiveness of a facility is dependent upon many variables. The deterioration rate of facility components; the am﹄ t of this deterioration arrested through preventive and cyclical maintenance; the amount of unknown, unseen, and nonreversible deterioration; facility layout and location; ana satisfaction and performance of the workers are felt to be the major determinants of facility ineffectiveness. These variables are manifest by increased O&M costs, increased personnel costs, low productivity, low morale, and reduced output.

Of the relevant costs described in this chapter, only O&M costs are readily measurable at present. Even Air Force O&M costs are not automatically collected in the desired form (i. e., by individual

facility). So, to adequately consider all the relevant costs described by this chapter is no easy matter. However, the importance of their consideration, whether quantitatively or qualitatively, cannot be over-emphasized.

Measurability of these relevant costs may improve in the future with the implementation of the RMS concept. The increasing interest in designing work environments with man as the key ingredient should prove useful in improving operational efficiency within the Air Force.

As previously stressed, the importance of this discussion is that these cost factors be recognized for what they are--real costs associated with every facility being evaluated to determine its economic superiority. In order to increase the overall efficiency within the Department of Defense, a cognizance of these costs and their effects is required.

This chapter has presented the relevant costs to be considered in determining the economic life of a facility. To provide the reader with an understanding of these costs, the discussion has focused on the determinants of the relevant costs and their interrelationships. The following chapter illustrates the effect of considering all the relevant costs discussed in this chapter on the facility replacement decision.

CHAPTER IV

ECONOMIC ANALYSIS

Economic Analysis Defined

At the outset of this research effort, economic analysis was defined as "a systematic approach which assists the manager in obtaining a solution to a given problem based on a thorough evaluation of the costs and benefits of various alternatives available to accomplish desired objectives." (14:5) It is important that this definition now be expanded to provide the reader with a better understanding of the individual aspects which, in aggregate, form an economic analysis.

Economic analysis is a management decision-making process that encompasses the explicit, scientific methods of analysis in the proposed application of one's resources toward a stated objective. Explicitness is essential to any scientific method in that the process of making a decision is consciously carried through and all the elements and steps in the process are spelled out. Explicitness allows replication and review by others and a basis for improving on bad decisions.

Basic to any decision process is the identification of alternatives. The facility replacement decision, as discussed herein, is limited to three alternatives:

1. Retain the facility "as is" and continue to maintain it.

2. Rehabilitate the facility by bringing it up to current standards in terms of layout and technology.

3. Replace the entire facility with an up-to-date, modern, technologically sufficient facility.

From an economic decision viewpoint, the alternatives identified above require a common denominator for comparison and a decision rule to determine rank ordering of the alternatives. The common denominator used in the ensuing analysis is the present value of all future costs and the decision rule is to minimize total present value costs. Benefits associated with any alternative are considered in terms of costs in competing alternatives.

Time Value of Money

Because of the time value of money, a dollar today has a value, termed a "present value," which is more than the prospect of a dollar next year or ten years from now. This is true, assuming constant prices, because of the interest accorded money in the market place.

> ... Any amount of resource withheld from current consumption and invested in future goods- and service-producing capital will result in command over an increased amount of consumption in the future by a factor of i, the market rate of interest, assuming constant prices. (40:353)

Money may be invested or deposited in the private sector of the economy and interest will be paid for use of the deposited amount. On the other hand, if money is spent, the interest obtainable by investment is foregone. The loss of interest must be accepted as a necessary cost

of expenditure. Because of the potential of interest, money commanded today has a greater value than the same amount commanded in the future. Thus, one dollar in the future is "equivalent" to less than one dollar today. Grant and Ireson describe the concept of equivalence as:

> Given an interest rate, we may say that any payment or series of payments that will repay a present sum of money with interest at that rate is equivalent to that present sum. Therefore, all future payments or series of payments that would repay the same present sum with interest at the stated rate are equivalent to each other. (18:40)

Because of the time value of money, costs that occur over future years cannot be compared directly to the dollar value of costs in the present. It is necessary, therefore, to express the dollar value of proposed costs to be incurred over a number of years in the future in terms of "today's" dollar value. This can be accomplished through the use of the single payment present value factor.

The single payment present value factor translates the dollar value of future costs into present monetary equivalents. This factor is a function of a specified interest rate and the number of periods, usually years, in the future that the cost is incurred.

The present value concept and the present value factor is developed mathematically in the following manner. Let S designate a future sum which is equivalent to a present sum P. Thus, S is a sum of money, n, interest periods from the present which is equivalent to P at interest rate i. This relationship is expressed mathematically as:

(4. 1) $S = P (1 + i)^n$

Determining the present value of a future amount (either investment or cost), is simply a matter of dividing both sides of equation (4. 1) by $(1 + i)^n$. The resulting formula

(4. 2) $P = S \dfrac{1}{(1 + i)^n}$

provides the present value, P, of a future cost, S, at the interest rate i, n periods in the future. The term $\dfrac{1}{(1 + i)^n}$ is the single payment present value factor.

As an example, if a cost of $100 is to be incurred three years from now and money invested now would earn 10 per cent annual interest, what is the present worth of that future cost? Using equation (4. 2),

$$P = S \frac{1}{(1 + i)^n}$$

$$P = \$100 \frac{1}{(1 + 0. 10)^3}$$

$$P = \$75. 13$$

the present value of a cost to be incurred 3 years from now is $75. 13. That is to say, if $75. 13 were invested now, its value three years hence would be $100.

The Decision Alternatives

The present value model developed will allow the decision authority to determine the economically superior alternative of the three under consideration. The model is not designed to answer the

question of _when_ to replace or rehabilitate, but rather to determine
the economically superior present value alternative at the time the
analysis is undertaken.

The specific definition of each alternative in a replacement con-
sideration is now addressed in greater detail. Obviously, "to do
nothing" and continue to operate and maintain a facility in its current
configuration is a possible decision. The "do nothing" decision, how-
ever, should be based on a knowledge of the total future costs involved
in the continued use of a facility. If this alternative is truely the
economically superior when compared to the rehabilitation or replace-
ment alternatives, it is the correct decision.

The term rehabilitation, as used herein, applies to modernization
of the facility to bring it into conformity with current construction and
functional standards. The basic purpose of rehabilitation is to offset
the effects of deterioration and obsolescence. Rehabilitation has the
basic effect of extending the economic life of a facility by reducing
future operation and maintenance costs and improving the efficiency of
the function which operates from within the facility. Rehabilitation
could include such things as:

1. Increasing the capacity of the facility's electrical distribution
   system.

2. Installation of an improved lighting system.

3. Rearrangement of partitions to improve the functional layout.

4. Installation of air conditioning.

5. Installation of sound attenuation materials.

6. Carpeting.

7. Installation of a more efficient heating system.

8. Installation of suspended acoustical tile ceiling.

The replacement alternative would provide a newly constructed facility designed to provide the highest possible degree of functional efficiency. The replacement facility is also designed to modern construction standards which will result in reduced future operation and maintenance costs.

The Facility Replacement Model

The authors' experience indicates that within the Air Force the facility replacement decision seldom explicitly considers the "total" costs involved in the alternatives to continued use of a facility. Therefore, the objective in the development of the facility replacement model which follows is to establish a mathematical model which expresses the relationship of all pertinent variables so that a rational decision can be made.

The authors' realize that quantification of the relevant costs discussed in chapter III is a major problem in itself. However, ignoring their existence because of the difficulty of their determination is tantamount to assuming that they do not exist. The model to be developed herein draws its worth from the insight it will provide of the relationship and interaction of the relevant cost factors. Recognition of the sensitivity of each of the relevant cost factors is essential to a creditable determination of the economic life of a facility.

In the development of the replacement model, the assumption is made that the function occupying the facility will be required for a definite period, T, after which a requirement for the function will no longer exist. The question to be answered is, which of the available alternatives is economically superior based on the present value of all future costs?

Mathematically, the replacement model can be represented as:

$$PV_{alt\ k} = I_o + \sum_{n=1}^{T}\left(\frac{M_n}{(1+i)^n}\right) + \sum_{n=1}^{T}\left(\frac{P_n}{(1+i)^n}\right) + \sum_{n=1}^{T}\left(\frac{O_n}{(1+i)^n}\right) - \frac{S_T}{(1+i)^T}$$
$$k=1,2,3$$

$$PV_{alt\ k} = I_o + \sum_{n=1}^{T}\left[\frac{1}{(1+i)^n}\left(M_n + P_n + O_n\right)\right] - \frac{S_T}{(1+i)^T}$$

Where:

$PV_{alt\ k}$ = the present value of all future costs of alternative k. $k=1,2,3$

I_o = the investment cost for the rehabilitation plus the present salvage value of the existing facility, or for replacement, the cost of the replacement facility less the current salvage value of the existing facility.

M_n = operation and maintenance costs in year n.

P_n = the cost of lost performance in year n.

O_n = the cost of obsolescence in year n.

S_T = the facility's salvage value in year T.

i = the interest rate.

T = the period of time that a facility will be required to support a specific function.

The replacement model developed above explicitly accounts for all the relevant costs outlined in chapter III. For purposes of

illustration, the costs due to obsolescence are shown separately rather than included in the costs of O&M and lost performance. Several assumptions are inherent in the use of the replacement model. These assumptions are:

1. Investment costs are one-time costs incurred at the beginning of the project.

2. Recurring costs are discrete, are incurred at equal intervals of one year, and disbursements are made at the end of the year.

3. The only positive cash flow is the salvage value. All other cash flows are costs.

4. Estimates of future costs can be made for all relevant costs for each future year for each alternative.

5. All alternatives considered will fulfill the mission requirements.

6. Funds are available to carry out the economically superior alternative.

7. The function occupying the facility will be required for a finite period.

Example of Facility Replacement Analysis

In order to illustrate the use of the present value model for a replacement analysis, the hypothetical data contained in tables 4-1 through 4-6 have been developed. Two separate analyses are accomplished, one considering the effect of operation and maintenance costs as the only relevant cost, and the second including all relevant costs as previously outlined herein.

Assume the following hypothetical situation. An aircraft maintenance facility has shown growing signs of inadequacy in its ability to

accommodate jet engine repairs. The existing facility is presently
twenty years old and, because of its poor configuration for the produc-
tion process, long delays are common in the servicing and repair
operation. It appears appropriate to investigate the economy of
continued use, rehabilitation, or complete replacement. It is esti-
mated that the requirement for this type of a facility will exist for only
twenty more years. The existing facility has a current salvage value
of $100,000. Its salvage value in twenty years will be $50,000. The
facility could be rehabilitated at an estimated cost of $100,000.
Alternatively, the facility could be completely replaced at a cost of
$350,000, which, after twenty years, would have a salvage value of
$200,000. A 10 per cent interest rate will be used as stipulated in
DODI 7041.3, 18 October 1972. Estimated annual operations and
maintenance costs for the three alternatives are shown in column 3 of
tables 4-1, 4-2, and 4-3.

The present value costs of the three alternatives are:

PV (continued use) = $213,448

PV (rehabilitate) = $261,555

PV (replacement) = $252,218

The appropriate choice, based on a decision rule of minimum
present value cost, is to do nothing, i.e., continued use of the existing
facility is the economically superior alternative.

Now, let us reassess our previous decision. Assume that the
original scenario remains unchanged except that the relevant costs of

TABLE 4-1

CONTINUE OPERATION "AS IS"
(O&M COSTS ONLY
CONSIDERED)

Column 1	Column 2	Column 3	Column 4* $\frac{1}{(1 + i)^n}$ $i = 10\%$	Column 5 (Col 3) · (Col 4)	Column 6 (Col 2) · (Col 4)
n	I_o	M_n			
0	$100,000	-	-	-	
1		$10,000	.9091	$ 9,091	
2		10,400	.8264	8,595	
3		10,850	.7513	8,152	
4		11,350	.6830	7,752	
5		11,900	.6209	7,389	
6		12,500	.5645	7,056	
7		13,150	.5132	6,750	
8		13,850	.4665	6,461	
9		14,600	.4241	6,192	
10		15,400	.3855	5,937	
11		16,250	.3505	5,695	
12		17,150	.3186	5,464	
13		18,100	.2897	5,244	
14		19,100	.2633	5,029	
15		20,150	.2394	4,824	
16		21,250	.2176	4,624	
17		22,400	.1978	4,430	
18		23,600	.1799	4,245	
19		24,850	.1635	4,063	
20	$ 50,000	26,150	.1486	3,885	$7,430
				$120,878	

$$PV_{alt\ 1} = \$100,000 + 120,878 - 7,430 = \$213,448$$

*Present value factors taken from (2).

TABLE 4-2

REHABILITATE (O&M COSTS ONLY CONSIDERED)

Column 1	Column 2	Column 3	Column 4* $\frac{1}{(1+i)^n}$ $i = 10\%$	Column 5 (Col 3) · (Col 4)	Column 6 (Col 2) · (Col 4)
n	I_o	M_n			
0	$200,000	-	-	-	
1		$ 7,000	.9091	$ 6,364	
2		7,200	.8264	5,950	
3		7,450	.7513	5,597	
4		7,650	.6830	5,225	
5		7,900	.6209	4,905	
6		8,100	.5645	4,572	
7		8,350	.5132	4,285	
8		8,550	.4665	3,988	
9		8,800	.4241	3,732	
10		9,000	.3855	3,470	
11		9,250	.3505	3,242	
12		9,450	.3186	3,010	
13		9,700	.2897	2,810	
14		9,900	.2633	2,606	
15		10,150	.2344	2,430	
16		10,350	.2176	2,252	
17		10,600	.1978	2,097	
18		10,800	.1794	1,943	
19		11,050	.1635	1,807	
20	$ 70,000	11,250	.1486	1,672	$10,402
				$71,957	

$PV_{alt\ 2} = 200,000 + 71,957 - 10,402 = \$261,555$

*Present value factors taken from (2)

TABLE 4-3

REPLACE (O&M COSTS ONLY
CONSIDERED)

Column 1	Column 2	Column 3	Column 4* $\dfrac{1}{(1+i)^n}$ $i = 10\%$	Column 5 (Col 3) · (Col 4)	Column 6 (Col 2) · (Col 4)
n	I_o	M_n			
0	$250,000	-	-	-	
1		$2,500	.9091	$ 2,273	
2		2,600	.8264	2,148	
3		2,750	.75:3	2,066	
4		2,900	.6830	1,980	
5		3,100	.6209	1,924	
6		3,350	.5645	1,891	
7		3,550	.5132	1,822	
8		3,750	.4665	1,749	
9		4,000	.4241	1,696	
10		4,250	.3855	1,638	
11		4,500	.3505	1,577	
12		4,800	.3186	1,530	
13		5,000	.2897	1,448	
14		5,250	.2633	1,382	
15		5,450	.2394	1,305	
16		5,700	.2176	1,249	
17		5,900	.1978	1,167	
18		6,150	.1799	1,106	
19		6,300	.1635	1,030	
20	$200,000	6,500	.1486	966	$29,720
				$31,938	

$PV_{alt\ 3} = 250,000 + 31,938 - 29.720 = \$252,218$

*Present value factors taken from (2).

performance loss and obsolescence are now as shown in tables 4-4,
4-5, and 4-6. The costs shown in these tables reflect the cost trends
discussed in chapter III. Costs for both performance loss and obsoles-
cence increase with age, but the relative magnitude of the costs are
reduced by rehabilitation or replacement. Based on the costs shown
in tables 4-4, 4-5, and 4-6, the present value costs of the three
alternatives are:

PV (continued use) = $326,844

PV (rehabilitate) = $307,623

PV (replacement) = $265,407

The appropriate choice, based on the decision rule of minimum
present value cost, has now shifted to the replacement alternative.
The difference in the present value cost of the "continued use" and
"replacement" alternatives is now significantly in favor of the replace-
ment.

Conclusions

The authors have shown that if one accepts the premise that
facilities experience obsolescence and ineffectiveness costs with
advancing age, that the replacement decision can be significantly
affected by an explicit consideration of the attendant costs. Obsoles-
cence and performance loss due to a facility's age are costs that must
be considered in a facility replacement decision. Although the measur-
ment of costs resulting from obsolescence and facility ineffectiveness

TABLE 4-4

CONTINUE OPERATION "AS IS"
(ALL RELEVANT COSTS
CONSIDERED)

Col 1	Col 2	Col 3	Col 4	Col 5	Col 6 $(Col3)+$ $(Col4)+$ $(Col5)$	Col 7* $\frac{1}{(1+i)^n}$ $i=10\%$	Col 8 $(Col6)\cdot$ $(Col7)$	Col 9 $(Col2)\cdot$ $(Col17)$
n	I_0	M_n	P_n	O_n				
0	$100,000							
1		10,000	8,000	2,500	20,500	.9091	18,636	
2		10,400	8,300	2,650	21,350	.8264	17,643	
3		10,850	8,650	2,800	22,300	.7513	16,753	
4		11,350	8,950	2,950	23,250	.6830	15,880	
5		11.900	9,250	3,050	24,200	.6209	15,025	
6		12,500	9,550	3,200	25,250	.5645	14,253	
7		13,150	9,800	3,300	26,250	.5132	13,471	
8		13,850	10,100	3,450	27,400	.4665	12,782	
9		14,600	10,300	3,600	28,500	.4241	12,087	
10		15,400	10,500	3,700	29,600	.3855	11,410	
11		16,250	10,800	3,850	30,900	.3505	10,830	
12		17,150	11,250	3,950	32,350	.3186	10,307	
13		18,100	11,600	4,100	33,800	.2897	9,791	
14		19,100	11,900	4,250	35,250	.2633	9,281	
15		20,150	12,200	4,300	36,650	.2394	8,774	
16		21,250	12,550	4,400	38,200	.2176	8,312	
17		22,400	12,850	4,550	39,800	.1978	7,872	
18		23,600	13,200	4,650	41,450	.1799	7,56	
19		24,850	13,500	4,750	43,100	.1635	7,046	
20	50,000	26,150	13,800	4,900	44,850	.1486	6,665	7,430
							234,274	

$PV_{alt\ 1} = 100,000 + 234,274 - 7,430 = \$326,844$

*Present value factors taken from (2).

TABLE 4-5

REHABILITATION (ALL RELEVANT
COSTS CONSIDERED)

Col 1	Col 2	Col 3	Col 4	Col 5	Col 6 (Col3)+ (Col4)+ (Col5)	Col 7* $\frac{1}{(1+i)^n}$ i = 10%	Col 8 (Col6)· (Col 7)	Col 9 (Col 2)· (Col 7)
n	I_o	M_n	P_n	O_n				
0	\$200,000							
1		7,000	3,000	1,000	11,000	.9091	10,000	
2		7,200	3,000	1,050	11,250	.8264	9,297	
3		7,450	3,100	1,100	11,550	.7513	8,678	
4		7,650	3,200	1,150	12,000	.6830	8,196	
5		7,900	3,300	1,200	12,400	.6209	7,700	
6		8,100	3,450	1,300	12,850	.5645	7,254	
7		8,350	3,550	1,400	13,300	.5132	6,825	
8		8,550	4,100	1,500	14,150	.4665	6,600	
9		8,800	4,200	1,650	14,650	.4241	6,213	
10		9,000	4,350	1,750	15,100	.3355	5,821	
11		9,250	4,450	1,850	15,550	.3505	5,450	
12		9,450	4,500	2,000	15,950	.3186	5,082	
13		9,700	4,650	2,150	16,500	.2897	4,780	
14		9,900	4,750	2,300	16,950	.2633	4,463	
15		10,150	4,900	2,450	17,500	.2344	4,190	
16		10,350	5,100	2,600	18,050	.2176	3,928	
17		10,600	5,500	2,750	18,850	.1978	3,728	
18		10,800	5,700	2,900	19,400	.1749	3,490	
19		11,050	5,900	3,000	19,950	.1635	3,262	
20	70,000	11,250	6,200	3,200	20,650	.1486	3,068	10,402
							118,025	

$$PV_{alt\ 2} = 200,000 + 118,025 - 10,402 = 307,623$$

*Present value factors taken from (2).

TABLE 4-6

REPLACEMENT (ALL RELEVANT
COSTS CONSIDERED)

Col 1	Col 2	Col 3	Col 4	Col 5	Col 6 (Col3)+ (Col4)+ (Col5)	Col 7* $\frac{1}{(1+i)^n}$ i=10%	Col 8 (Col6)· (Col7)	Col 9 (Col2)· (Col7)
n	I_0	M_n	P_n	O_n				
0	$250,000							
1		2,500	0	0	2,500	.9091	2,272	
2		2,600	0	0	2,600	.8264	2,149	
3		2,750	100	150	3,000	.7513	2,254	
4		2,900	150	300	3,350	.6830	2,288	
5		3,100	200	450	3,750	.6209	2,328	
6		3,350	300	650	4,050	.5645	2,286	
7		3,550	400	850	4,800	.5132	2,463	
8		3,750	500	1,050	5,300	.4662	2,471	
9		4,000	650	1,200	5,850	.4241	2,480	
10		4,250	800	1,400	6,450	.3855	2,486	
11		4,500	950	1,550	7,000	.3505	2,453	
12		4,800	1,100	1,700	7,600	.3186	2,421	
13		5,000	1,250	1,850	8,100	.2897	2,346	
14		5,250	1,350	2,000	8,600	.2633	2,264	
15		5,450	1,500	2,200	9,150	.2394	2,191	
16		5,700	1,600	2,500	9,800	.2176	2,132	
17		5,900	1,750	2,800	10,450	.1976	2,065	
18		6,150	2,000	3,000	11,150	.1799	2,006	
19		6,300	2,300	3,200	11,800	.1635	1,929	
20	200,000	6,500	2,500	3,400	12,400	.1486	1,843	$29,720
							45,127	

$$PV_{alt\ 3} = 250,000 + 45,127 - 29,720 = \$265,407$$

*Present Value factors taken from (2)

is difficult, their effect on the sensitivity of the previous economic

analysis illustrates the importance of their consideration, even if the

consideration is qualitative.

CHAPTER V

DEFERRED MAINTENANCE

To this point, the thrust of this research effort has been directed
toward assessment of the effects of relevant costs on the facility
replacement decision. The magnitudes of future maintenance costs in
any replacement consideration are of necessity estimates. These costs
represent the resources needed to provide required facility support
over the anticipated life of the facility. These estimates are made by
lower level resource managers who lack (1) the authority to allocate
funds to accomplish all maintenance requirements, (2) the knowledge of
total Air Force resource requirements, and (3) the capability of
comparing the benefits associated with their requirements to the
benefits associated with other Air Force requirements.

After the investment is made, changing conditions often render the
original estimates invalid. These changing conditions can be brought
about by technological changes in the facility or function, changes in
personnel responsible for determining actual maintenance require-
ments, and/or the realignment of priorities which govern the allocation
of total Air Force resources. Because of these changing conditions,

a variance often results between anticipated and actual maintenance requirements. That is to say, maintenance requirements normally exceed the resources available for their accomplishment.

Since the allocation of total Air Force resources is presumably made based on the expectation of achieving maximum benefits from expenditures, the base civil engineer should have a means of assessing the benefits to be derived from maintenance expenditures. The authors feel that the concept of facility ineffectiveness, as previously discussed in terms of replacement considerations, should be extended to the day-to-day application of maintenance resources. The concept of facility ineffectiveness and loss of performance is now addressed in terms of deferred maintenance requirements.

As previously discussed, deterioration is a physical phenomenon which occurs over time to the ageable materials from which a facility is constructed. The rate and magnitude of deterioration is not easily determined nor is deterioration itself possible to reverse in some cases. The effect of deterioration is a worsening of the physical condition of the facility. Maintenance is the balancing force which forestalls but cannot prevent deterioration.

As suggested earlier, there is an attendant cost, other than maintenance costs, to uncorrected deterioration. That is to say, a reduction in performance level or output, from that previously determined to be the optimal, is experienced by the function occupying the facility.

Given that all maintenance requirements are accomplished, the only contributers to the loss in performance would be the unseen, nonreversible and not economically correctable forms of deterioration. Usually, however, maintenance requirements exceed available resources and the level of maintenance provided does not fulfill all requirements. Therefore, a backlog of maintenance requirements results. This can result in an increased rate of deterioration. Due to this uncorrected deterioration, the working environment can be degraded causing a reduction in the quantity or quality of output from the function. This reduction in output reflects the cost of lost performance and indicates a reduction in the function's effectiveness and/or efficiency.

The total annual maintenance required to return the facility to a condition suitable for optimal production is that maintenance required which over the anticipated life of the facility would be less in terms of present value than the cost of deterioration which it forestalls. Once a backlog exists, the loss in functional performance is continuously accumulating and represents the benefit to be derived from accomplishment of the backlogged maintenance requirements. This loss in performance, as will be shown, should be the determining factor in deciding upon the most efficient application of maintenance resources.

At present, the Air Force classifies deferred maintenance in one of two categories:

Backlog of Essential Maintenance and Repair (BEMAR).
Maintenance and repair over $1000 required in the
current or prior fiscal years that cannot be accomp-
lished during the current fiscal year due to lack of
resources. An item is considered to be essential
when delay for inclusion in a future program will
impair the military readiness and capability, or
cause significant deterioration of real property
facilities. (48:18-4)

Delayed Maintenance and Repair. Maintenance and
repair required in the current or prior fiscal years
that cannot be accomplished during the current fiscal
year due to lack of resources. This work is required
to bring the facility to a proper condition and does not
satisfy the definition of BEMAR. (48:18-4)

In the definitions above, the distinction between "BEMAR" and

"Delayed" (interpreted as essential and nonessential respectively) is

dependent upon the interpretation of several rather subjective condi-

tions. That is to say, who is to determine whether, and to what

degree, a leaky roof on the base chapel impairs military readiness

and capability? Certainly the chaplain has one view and the operational

commander has another. Their separate views of "essentiality" are a

function of their frames of reference. The inherent inadequacy of the

present definition of "essentiality," as regards the backlog of mainte-

nance requirements, lies in the lack of definition of what constitutes

"impairment of military readiness and capability" or "significant

deterioration." For this reason, the authors feel that the concept of

facility ineffectiveness and its relevant cost as discussed in chapter III,

can be used to provide a better understanding of what a backlog of

maintenance actually represents.

A backlog of maintenance requirements is the result of requirements exceeding resources available. Under these conditions, one must establish some method of allocating resources so as to reap maximum benefits in terms of efficiency and effectiveness. In any military organization such as the Air Force, it has been determined that all functions within the current Air Force organizational structure are required to carry out the overall Air Force "mission." Otherwise, why would they exist? Although all may be required to carry out the "mission," it is obvious that there are relative degrees of importance associated with each function based upon its level of support to the overall Air Force mission. In this context, it must be assumed that available maintenance resources are applied to functions in a manner that will provide the maximum benefit toward the accomplishment of the Air Force mission.

Returning to the concept of facility ineffectiveness and the attendant loss of performance, it would seem appropriate then that each maintenance requirement should be assessed to determine the benefits to be derived from its accomplishment. The benefits should be determined based on the relative mission importance of the function and the magnitude of the loss of performance which can be forestalled by accomplishment of the required maintenance. The cost of each maintenance requirement should then be compared against the present value of all benefits to be gained by its accomplishment. Only those requirements for which the present value of all benefits exceeds the cost of

accomplishment would be considered for current fiscal year funding.

Those requirements for which resources are not available and whose

present value benefits exceed the cost of accomplishment would be

considered essential. All other requirements for which resources are

not available would be considered nonessential. Based on the foregoing

discussion, the authors suggest the following definitions:

> Backlog of Essential Maintenance and Repair (BEMAR).
> Maintenance and repair required in the current or prior fiscal
> years that cannot be accomplished during the current fiscal
> year due to lack of resources. An item is considered to be
> essential when its cost is less than the present value of the
> performance loss which its accomplishment will forestall.

> Delayed Maintenance and Repair. Maintenance and repair
> required in the current or prior fiscal years that cannot be
> accomplished during the current fiscal year due to lack of
> resources. The cost of these requirements exceeds the
> present value of the performance loss which their accomp-
> lishment will forestall.

In the definitions above, the assumption is made that performance

loss can be measured. Although quantitative performance measure-

ment is a goal of the proposed resource management system (RMS),

it is not possible today. At present, measurement of functional per-

formance is a subjective consideration accomplished by the Inspector

General.

The objectives of the suggested definitions above are to emphasize

the consideration of increased efficiency and effectiveness for all

Air Force functions and to obtain optimal allocation of available

maintenance resources.

Because of the current Air Force definition, BEMAR is presently viewed as the cost to correct physical deterioration. In addition, the effects of facility deterioration on worker morale, productivity, and functional performance must be recognized.

Since a backlog of maintenance requirements which impacts on "military readiness and capability" presently exists, it must be assumed that these requirements were considered along with others competing for available funds and the decision was made at some level that the available funds could be more effectively applied elsewhere. If the means were available to measure all competing programs based upon their contribution to mission effectiveness and efficiency, the Air Force would be assured of optimal allocation of resources.

When determined in terms of the authors' definition, the BEMAR would measure not only the amount of facility deterioration which has been allowed to go uncorrected, but also the resultant effect of this unaccomplished maintenance on mission accomplishment. This information, when presented as justification for additional maintenance funding, could be of tremendous assistance to the resource manager in obtaining the necessary funds to provide a suitable working environment for accomplishment of the mission. Therein lies the worth of the preceding discussion of BEMAR.

CHAPTER VI

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS
FOR FURTHER RESEARCH

Summary

This study begins with a recognition that increased functional

efficiency and effectiveness are required throughout the Department of

Defense. As the designated Air Force managers of real property

assets, the Air Force civil engineer must ensure that economic

rationale is used in the overall management of the real property inven-

tory. Under certain circumstances, it may be more economical to

replace or rehabilitate an aging real property facility. A decision of

this nature must be based on an explicit assessment of the benefits

and costs associated with each alternative method of providing facility

support. Such an assessment comprises an economic analysis of the

facility replacement decision.

Economic analysis can only be carried out when one is fully aware

of all the relevant costs. Consequently, this study focuses on the

causes, effects, and analysis of the relevant costs in the facility

replacement decision. In Chapter II, the use of multiple regression

analysis is illustrated as a method of determining future maintenance

83

costs based on historical data. In Chapter III, the effects of deterioration, obsolescence, and facility ineffectiveness are discussed as determinants of operation and maintenance costs, lost performance costs, and salvage value. In Chapter IV, a present value analysis of future costs of the continued use, rehabilitation, and replacement alternatives is accomplished to illustrate the sensitivity of the decision criteria to the inclusion of obsolescence and lost performance costs. In Chapter V, the effects of maintenance funding constraints are assessed in terms of the attendant functional performance losses which can be expected when maintenance requirements exceed available resources.

Conclusions

The regression analysis accomplished in Chapter II shows that for the population considered, there is a positive correlation between a facility's age, size, and functional use and the amount expended annually on its maintenance. The results of the regression analysis also show that there are many other factors which undoubtedly influence the facility's annual maintenance expenditures. The regression equation developed in Chapter II is limited in application to the population from which it was developed; however, the regression procedures used are sound and are certainly applicable, within the bounds of their assumptions, to any Air Force installation.

The facility replacement decision encompasses a multitude of interrelated considerations which are both difficult to isolate and difficult to evaluate in aggregate. Based on the authors' research and the discussions herein, it is concluded that in isolation the concepts of deterioration, facility ineffectiveness, and obsolescence are major determinants of the relevant costs associated with the economic life of any capital asset.

The attendant costs of deterioration, facility ineffectiveness, and obsolescence can and indeed must be considered when assessing the economic life of a facility within the Air Force.

Research has shown that the relevant costs discussed herein are valid when evaluating the proposed replacement of production equipment in private industry. Their validity is not reduced by extension to Air Force facility replacement considerations. Although, admittedly, the complexity of their assessment and measurement becomes more difficult in public sector facility replacement consideration, their basis in fact should not be ignored.

Although increasing operation and maintenance costs of a facility over time represent important factors in the facility replacement decision, the continuing costs of reduced functional effectiveness due to a facility's inability to provide an adequate working environment may well be the major cost.

The benefit of dissecting each of the relevant costs identified herein lies not only in the increased understanding of each in isolation, but

more importantly in understanding the effects of these costs in aggregate on the facility replacement decision. The application of the facility replacement cost model developed in Chapter IV shows that the explicit consideration of the costs of facility ineffectiveness and obsolescence can significantly affect a facility replacement decision.

The recognition of the benefits obtainable, in terms of functional performance, from funds expended in the construction, rehabilitation, or maintenance of Air Force facilities is of paramount importance if functional effectiveness and efficiency are to be attained in the Air Force today. Toward this end, a facility should be replaced or rehabilitated only when the present value of all its future costs exceeds the present value of all future costs to replace or rehabilitate it.

Although the timely replacement or rehabilitation of aging facilities is important when they have reached their economic lives, this study would have been incomplete if it had not addressed the effects and meaning of backlogged maintenance requirements whose accomplishment is precluded by budgetary constraints. Based on the discussion in Chapter V, the authors conclude that the current Air Force definition of the Backlog of Essential Maintenance and Repair (BEMAR) is nondescript, and that in reality BEMAR represents a potential improvement in functional performance which is foregone by a failure to accomplish required maintenance.

Recommendations for Further Research

In retrospect, the authors realize the total complexity of the facility replacement decision. In several areas, this thesis has merely "scratched the surface." For this reason, the authors recommend the following additional areas of research which would contribute immensely to a further understanding of the facility replacement decision:

1. Determination of additional relevant variables and their effect on Air Force facility annual maintenance requirements and expenditures.

2. Determination of the effects of facility conditions on functional performance.

3. Further development of the relationship between BEMAR and the potential improvement in functional performance.

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